NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-HFM-233**

Sensitive Equipment Decontamination

(Décontamination du matériel sensible)

This report provides a survey on current and future technologies for the CBRN decontamination of Sensitive Equipment and evaluates the capabilities of the different technologies to counter today's and tomorrow's CBRN threats. The document was elaborated by a group of scientists and CBRN specialists, all being members of the Hazard Management Panel within NATO Joint CBRN Defence Capability Development Group.

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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Sensitive Equipment Decontamination

(STO-TR-HFM-233)

Executive Summary

From a doctrinal point of view, decontamination is "the process by which the hazard from chemical, biological, radiological and nuclear substances is reduced or removed". Along with avoidance and protection, decontamination is an essential part of CBRN Defence, hence Force Protection.

During recent asymmetric operations, many NATO Nations have focused attention and resources on other aspects of Force Protection. As a result many NATO Nations have military equipment that, whilst vital to the Alliance's operational capability, has not been subjected to any CBRN hardening due to other priorities, such as fast procurement timelines or threat prioritisation. Such equipment, hereinafter referred to as "Sensitive Equipment" (SE), may require special handling and treatment if it is to be decontaminated after a CBRN event. The purpose of this study was to research current and future technologies for the CBRN decontamination of Sensitive Equipment and evaluate whether the Alliance's capabilities in this area are adequate to counter today's and tomorrow's CBRN threats. This study was executed by a group of 8 authors, all being members of the Hazard Management Panel of the Joint CBRN Defence Capability Development Group under NAAG; the study director was the Chairperson of the JCBRND-CDG. The limitations lie with the fact that there was no full-time study director available and that the classification of the study had to be "NATO UNCLASSIFIED", the last restriction being quite serious.

Here, it had to be taken into consideration that NATO forces superiority today is to a large extent based on technological rather than numerical superiority. If C3 or C4I capabilities, which are typically executed using sensitive technical equipment, are severed by a CBRN attack, NATO forces will fall back to the same technological level as the adversary, maybe even lower. The actual threat of "low, slow, small" describes an easy method for an opponent to attack these capabilities by delivering a CBRN payload with little technological skills. The lack of hardening of equipment contributes to this vulnerability.

Taken into consideration from an early design step, hardening is not a highly cost-driving factor. In times of multiple low-intensity, asymmetric conflicts it seems the logical solution to generally identify mission-critical classes of equipment and to develop these in a way that they are decontaminable with respect to expected CBRN and TIH contamination.

At first sight this seems to be an activity calling for national solutions; however, given NATO's pursuit of interoperability, we recommend that an approach under the auspices of the Framework Nations Concept or the SMART DEFENCE INITIATIVE is much better suited in order to ensure maximum interoperability in Alliance operations.

A comprehensive analysis of the facts leads to the conclusion that, as of today, there is not yet a technological capability gap with respect to the decontamination of Sensitive Equipment. However, the Alliance, at this time, has at its disposal only limited capacities for the CBRN decontamination of Sensitive Equipment. This is due to the CBRN threat widely not being recognized for what it is – a tool, easily available even for a very low-tech opponent, to severely reduce the technological superiority of NATO forces in a conflict.

The magic solution of a universal technical decontamination solution to decontaminate all kinds of equipment from all kinds of hazards is not available and will not be available within the next 10 – 15 years.

The results of this study lead to the conclusion that, beyond continuing to observe the market and wait for industry to develop new, innovative technologies, NATO would be quite well-advised to invest in research in this area.

Décontamination du matériel sensible

(STO-TR-HFM-233)

Synthèse

Dans la doctrine, la décontamination est définie comme suit : « procédé permettant de réduire ou de supprimer le danger posé par des substances chimiques, biologiques, radiologiques et nucléaires ». Outre la prévention et la protection, la décontamination est une composante essentielle de la défense CBRN, et donc de la protection des forces.

Lors d'opérations asymétriques récentes, beaucoup de pays de l'OTAN ont concentré leur attention et leurs ressources sur d'autres aspects de la protection des forces. Par conséquent, de nombreuses nations de l'OTAN disposent de matériel militaire qui, bien que crucial pour les fonctionnalités opérationnelles de l'Alliance, n'a pas fait l'objet d'un durcissement CBRN en raison d'autres priorités, liées aux délais de passation des marché serrés ou à la priorisation des menaces. Ce matériel, ci-après appelé « Matériel Sensible » (MS) peut devoir faire l'objet d'une manipulation et d'un traitement spéciaux s'il devait être décontaminé après un événement CBRN. L'objectif de cette étude consistait à rechercher les technologies présentes et futures en matière de décontamination CBRN de Matériel Sensible et d'évaluer si les capacités de l'Alliance dans ce domaine sont adaptées pour faire face aux menaces CBRN actuelles et futures. L'étude a été menée par un groupe de huit auteurs, tous membres du panel de gestion des dangers du groupe interarmées de développement des capacités de défense CBRN (JCBRND-CDG) du NAAG (*NATO Army Armaments Group*) ; le directeur de l'étude était la personne qui préside le JCBRND-CDG. Les limitations concernaient l'absence de directeur à temps plein pour l'étude et le fait que la classification de l'étude devait être « OTAN SANS CLASSIFICATION », ce qui a constitué une restriction plutôt sérieuse.

Il convenait de tenir compte du fait que la supériorité actuelle des forces de l'OTAN est dans une large mesure technologique plutôt que numérique. Si des ressources C3 ou C4I, reposant en général sur du matériel technique sensible, subissaient une attaque CBRN, les forces de l'OTAN se retrouveraient au même niveau technologique que leur adversaire, et peut-être même à un niveau inférieur. La menace réelle du « bas, lent, petit » décrit une méthode facile qu'un opposant peut adapter pour s'en prendre à ces ressources, en mettant en œuvre une charge utile CBRN en s'appuyant sur des compétences technologiques limitées. Le manque de durcissement du matériel contribue à cette vulnérabilité.

S'il est pris en compte dès les premières phases de la conception, le durcissement n'est pas un facteur de coût très déterminant. En cette ère de conflits asymétriques multiples et de faible intensité, la solution logique semble être en général d'identifier les catégories de matériel critiques pour les missions et de les développer de sorte à ce qu'elles puissent être décontaminées, eu égard aux menaces CBRN et TIH potentielles.

A première vue, cette activité semble appeler des solutions nationales ; cependant, du fait de l'objectif d'interopérabilité de l'OTAN, nous recommandons que cette approche soit placée sous l'égide soit du Concept des Nations Cadres soit de l'INITIATIVE SMART DEFENCE, qui sont bien mieux adaptées pour garantir une interopérabilité maximale des opérations de l'Alliance.

Une analyse complète des faits permet de dégager la conclusion que, pour l'heure, il n'existe pas encore de fossé technologique en termes de décontamination du Matériel sensible. Cependant, l'Alliance ne dispose actuellement que de capacités limitées en termes de décontamination CBRN du Matériel sensible. Cela s'explique par le fait que la menace CBRN n'est largement pas reconnue pour ce qu'elle est – à savoir un

outil, facilement disponible même pour les adversaires disposant de peu de moyens techniques, permettant de réduire drastiquement la supériorité technologique des forces de l'OTAN lors d'un conflit.

La panacée, qui serait une solution technique universelle de décontamination permettant de décontaminer tous les types de matériel face à tous les types de dangers, n'existe pas encore mais pourrait voir le jour dans les 10 à 15 prochaines années.

Les résultats de l'étude mènent à la conclusion que, outre continuer à observer le marché et à attendre que le secteur développe des technologies tant inédites que novatrices, l'OTAN serait plutôt bien inspirée de poursuivre ses recherches dans ce domaine.

Chapter 1 – INTRODUCTION

1.1 GENERAL INTRODUCTION

This chapter is intended to lay a missing common ground by defining those terms that are ambiguously or not at all defined in the respective NATO doctrine.

1.1.1 Definitions

To ensure a common understanding of technical terms throughout this report, the definitions of two significant terms have to be clear – these terms are "Hazard Management" and "Sensitive Equipment".

1.1.1.1 Hazard Management

Hazard Management is one of the enabling components of CBRN defence[1]. Hazard Management includes a number of activities:

- Hazard Reduction/Survivability;
- Pre-Hazard Precautions;
- Hazard Avoidance;
- Hazard Control;
- Decontamination; and
- CBRN Waste Management.

AEP-7 mandates that military equipment should be hardened to withstand CBRN substances and that it should be decontaminable. However this policy has not always been applied rigorously. Some of the decontaminants used to carry out the decontamination process may be particularly damaging to certain equipments, particularly where they have not been designed with hardening and decontaminability in mind. Some military equipment will be Commercial-Off-The-Shelf (COTS) procurements where factors such as hardening and decontaminability will not have been included in the original specification. Where equipment has not been designed with hardening and decontaminability in mind, then care must be taken over the method of decontamination.

1.1.1.2 Sensitive Equipment

Firstly, it must be kept in mind that the term "decontamination" does not necessarily imply the destruction of the contaminant. AAP-21(B) defines decontamination as "the employment of chemical, biological or mechanical processes to remove or neutralize chemical, biological or radioactive materials". This NATO interpretation, however, differs from most Nation's interpretation of this term. Moreover, it clearly is desirable to destroy chemical or biological contamination to the point that it imposes no further risk to the operator or the environment. To align with both NATO terminology and national interpretation, the degree of decontamination (immediate, operational, or thorough) obtained will be linked to the respective technologies.

Secondly, there is no common understanding of the term "Sensitive Equipment"; the NATO Terminology Management System does not contain the term.

[1] AJP 3.8 CBRN defence-enabling components include detection, identification and monitoring, information management, physical protection, hazard management and medical countermeasures.

There are two documents one would think should supply such a definition:

- AAP-21(B)/STANAG 2367, (cancelled), NATO GLOSSARY OF CBRN TERMS AND DEFINITIONS.
- ATP 3.8.1 Vol. I / STANAG 2521, CBRN DEFENCE ON OPERATIONS.

AAP-21(B) does not mention the term Sensitive Equipment (SE) at all. ATP 3.8.1, Vol. I, mentions the term in several locations, e.g.:

> "1018. 13.d. Small Sensitive Equipment is particularly difficult to decontaminate, and often replacement of assemblies is the only solution."

However, no clear definition is provided. Hence, this Group feels free to accept the definition given in AEP-7/STANAG 4521 ED 5. Numeral 0202:

> "0202. Sensitive Equipment. Sensitive Equipment (SE) includes those items that cannot be decontaminated by commonly used methods such as aqueous or organic-based liquid decontaminants, without degradation of the item's performance and require special handling or treatment. SE is also material or equipment which can be considered as "critical" for mission performance, such as their functions being indispensable to the effective operation of the system."

1.1.1.3 Technology Readiness Levels (TRLs)

The TRLs of the technologies and procedures described in this document are based upon the definitions published in Ref. [1] – they are provided below in Table 1-1.

Table 1-1: Definition of Levels of Technical Readiness.

TRL	Definition	Description
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.

TRL	Definition	Description
5	Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an air-craft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

1.1.2 Survivability Considerations

AEP-7 recommends that Sensitive Equipment be developed with the decontamination process already in mind, in other words that the material is chosen appropriately:

> *"The decontamination of Sensitive Equipment should be planned early during the system design phase. The components and materials to manufacture the system should be as CBRN resistant as possible for survivability of the system and the crewmembers. Some materials are considered sensitive because of their chemical composition and position within the system, such as the interface between sensitive electronics. The SE may not be resistant to exposure to CBRN substances or amenable to common decontamination processes and the equipment performance could be degraded. Also, the decontamination solutions or other processes may not achieve effective decontamination of the equipment because the decontaminant cannot physically reach the contaminant on or within the SE to destroy or remove it, and a residual hazard remains."*

While this might have been a suitable approach when NATO started to re-write AEP-7 seven years ago, the playground has changed significantly. During the Cold War, the threat of a non-conventional conflict, i.e., using Weapons of Mass Destruction (WMD), was ever present. That in turn led to armament materiel being CBRN-hardened, that is, constructed in a way that this equipment could withstand the impact of a

CBRN event without loss of performance. The cost for hardening equipment to prescribed standards, obviously, is quite high, so that the requirement for hardened equipment was under permanent scrutiny.

1.2 APPROACH OF THIS STUDY

With the Cold War having ended, the perception of the CBRN threat has changed considerably. The risk of an all-out war, to include the use of WMD, vanished from the screen of public awareness. Following this decline of importance, the equipment entering military service has changed to be less and less rugged over the last decades.

Contributed to this effect has without a doubt the fact that the challenges NATO forces have faced over the last years were not heavy on the side of unconventional threats.

Even if a materiel is not specifically hardened against CBRN contamination, it is generally possible to apply specific procedures to decontaminate this materiel. To do so, however, requires knowledge about the material(s) used in building the system. The issue of Sensitive Equipment decontamination gains importance through the fact that procurement tends to buy more and more COTS/MOTS (Military-Off-The-Shelf) equipment whenever possible and when no specific military set of requirements exist as it is often the case with radios, optronics, computers and the like. This means waiving the requirements for CBRN hardening since, considering the small numbers the military is usually buying compared with industrial customers, industry is not willing to invest into the hardening of commercial equipment. After the requirement for hardening has been largely dropped, more and more systems are built exclusively to performance specifications, not considering the materials used. Hence, even a laboriously developed decontamination procedure for a system might very well work only with this one system, it might not with others from a different production batch.

Thus, standard decontamination procedures become inapplicable, since these “classic” procedures more often than not use harsh, aggressive chemicals. This in turn increases the necessity to develop new decontamination procedures which are compatible with these materials.

There are basically two ways out of this dilemma – apply a trial-and-error decontamination process upon every single piece of equipment, and verify it’s being operational or not thereafter or, which seems promising at this time, develop new and innovative decontamination methodologies that will not harm any equipment; to ensure effectiveness, those could be combined with a decontamination control process.

This study takes the latter approach.

In accordance with AEP-7 and AEP-58, the following non-exclusive list lists materiel, which is considered Sensitive Equipment:

- Flight critical components within or on aircraft (helicopters, airplanes);
- Computers and electronics;
- Optical devices and, speaking more generally; and
- Components of a system comprised of materials with particular vulnerabilities to CBRN agents or decontamination processes or solutions.

There are quite a few commercially available systems and processes that claim to be able to decontaminate Sensitive Equipment. This claim, however, has to be closely scrutinized. If we stick to the above definition of SE, it becomes obvious that a lot of these processes are not fit for SE. This study will evaluate the applicability of currently available or fielded, respectively, as well as future technologies for SE decontamination.

To allow for maximum usability for the operational community, these systems and technologies are also evaluated with respect to their positions in the DOTMLPF-I – matrix that describes the requirements of a defined capability/ technology's requirements with respect to doctrine, organization, training, materiel, leadership, personnel, facilities, and interoperability.

This study approaches its aim by splitting the general issue, SE decontamination, in the three parts C, B, and R/N decontamination; this is due to the fact that respective procedures may largely vary due to the nature of the contamination. Each area in turn is divided into an inventory-taking and an outlook into the future, combined with the DOTMLPF-I-approach listed above.

1.3 REFERENCES

[1] "Technology Readiness Assessment (TRA) Guidance", United States Department of Defense, April 2011.

Chapter 2 – GENERAL AND DOCTRINAL ASPECTS

2.1 COMMANDER'S OPTIONS

Once a CBRN incident has occurred, the operational Commander has a number of options for dealing with contaminated Sensitive Equipment. These, not exhaustively, are:

- Replace the equipment/capability.
- Decontaminate the equipment/capability.
- Dispose of the equipment/capability.
- Contain the equipment/capability pending subsequent decontamination.
- Quarantine the equipment/capability.

2.2 DECONTAMINATION

There are a number of levels[1] of decontamination:

- Immediate Decontamination: Decontamination carried out by individuals upon becoming contaminated.
- Operational Decontamination: Decontamination restricted to specific parts of operationally essential assets and/or working areas, carried out in order to sustain operations.
- Thorough Decontamination: Decontamination carried out in order to permit the partial or total removal of individual protective equipment, with the aim of restoring operational tempo.
- Clearance Decontamination: Decontamination of materiel to a standard sufficient to allow unrestricted transportation, maintenance, employment or disposal.

The decision to decontaminate Sensitive Equipment will depend on a number of factors:

- Criticality of equipment – The effects of losing critical equipment or a whole platform to CBRN contamination can have wide ranging consequences on the conduct of the operation.
- Cost – The financial cost of decontaminating a piece of equipment versus the operational impact and financial cost of losing a piece of equipment / platform; including the associated cost of disposing of that contaminated piece of equipment should be considered.
- Availability of replacement – The availability of replacement equipment should be considered. Some items such as correctly zeroed weapons and correctly fitted respirators have additional resource costs associated with them rather than simply replacing the item.
- Security Classification of the Equipment – One option other than decontaminating an item is to dispose of it. This may not be possible if the equipment or its components have a high security classification; this includes not only hardware, but also software and cryptographic material contained within systems.

The method of decontamination of the Sensitive Equipment should consider the following factors:

- The decontaminant to be used and its likely impact on the Sensitive Equipment.
- The resources needed to carry out the chosen method.

[1] AJP 3.8 specifies immediate, operational, thorough and clearance decontamination.

- Which elements of the equipment are sensitive and which items may be removed and subjected to “normal” decontamination processes.
- Those elements of the Sensitive Equipment that must protected during the decontamination process.
- The time taken to carry out the process and thus the time that the Sensitive Equipment will not be available for use.
- Waste management of the decontamination process.
- Local environmental regulations and practices.
- National environmental regulations and practices[2].
- Operational Framework.

The operational-level framework is the high-level doctrinal terms defined in AJP-01 – Allied Doctrine, and there are five key functions that assist the Commander in both execution and visualisation. The five functions are:

- Shape;
- Engage;
- Exploit;
- Protect; and
- Sustain.

They should not be viewed as sequential or separate and distinct phases; they are doctrinally mutually supporting and interlinked.

Shape – Shaping is the manipulation of the operational environment to the Alliance’s advantage and to the disadvantage of an adversary. CBRN is a capability where an adversary can seek to deter and limit the Alliance’s freedom of action through the use of CBRN agents. CBRN Sensitive Equipment decontamination is conducted at the tactical level, but will enable the operational Commander to retain a situational awareness after a CBRN incident at the operational and strategic levels, by enabling ongoing use of key ISTAR and C2 equipment.

Engage – This function aims to attack the adversary’s will and cohesion. By enabling Sensitive Equipment decontamination not only will situational awareness be maintained, but so will combat power; thus allowing the operational Commander to use this combat power to attack the will and cohesion of the adversary.

Exploit – A Commander should exploit opportunities to seize and retain the initiative, or regain it once lost, in order to achieve the mission. A CBRN incident can threaten the Alliance’s freedom of action. CBRN Sensitive Equipment decontamination will help regenerate combat power and return to the operational Commander the full range of ISTAR and C2 equipment and help to regain the initiative through better situational awareness and the focused deployment of combat power.

Protect – Sensitive Equipment decontamination contributes to the Protect function in 2 ways:

- **Physical Component** – By enabling troops to decontaminate their Sensitive Equipment, notably weapon and IPE, it will reduce the physiological burden on personnel. This will contribute to the operational Commander’s ability to survive and operate in a CBRN environment whilst helping to maintain operational tempo.

[2] AEP-58 states that the environmental regulations of the sending Nations apply. If the Host Nations’ regulations are more stringent and the Host Nation wants them to apply, it is the Host Nations’ responsibility to undertake the necessary efforts.

- **Moral Component** – Having a capability to decontaminate troops, and their Sensitive Equipment, once they have been subjected to a CBRN attack will support the Moral component of fighting power. The knowledge that such a capability exists to reduce their exposure to CBRN agents and the time they spend "dirty", whilst maintaining a full range of capabilities, will help to preserve the moral cohesion and motivation of the force.

Sustain – Sensitive Equipment will contribute to the sustain function in 2 ways:

- **Physical Component** – Decontaminating Sensitive Equipment will enable the operational Commander to re-generate forces that can be used elsewhere in the battle space, whilst minimising the spread of contamination. Limiting the spread of contamination helps to maintain freedom of manoeuvre and the re-generation of force elements will help to maintain operational tempo. Being able to regenerate equipment will reduce the logistic drag on the force by reducing the number of spare systems the force will need to hold.
- **Moral Component** – Sensitive Equipment decontamination will help to sustain moral cohesion and motivation by allowing troops to decontaminate and operate critical systems, thus reducing their time in CBRN IPE and CBRN contaminated areas. More importantly it will allow troops to decontaminate items of their personnel kit, such as individual weapons and IPE.

2.3 LINES OF DEVELOPMENT

Doctrine – Although AJP 3.8 details policy on decontamination, it does not deal specifically with Sensitive Equipment decontamination. Nations will need to ensure that the requirement to conduct Sensitive Equipment decontamination is necessary for the conduct of the mission. Not only that there must be an understanding that "normal" decontamination methods may damage Sensitive Equipment; where there is no ability to conduct Sensitive Equipment decontamination, Techniques, Tactics and Procedures (TTPs) must be developed that mitigate this lack of capability. This may include:

- Redundancy – Having additional equipment that can be deployed in the place of the contaminated equipment.
- Hazardous Avoidance – Attempting to ensure that were possible the equipment does not get contaminated.

Organisation – As Sensitive Equipment decontamination is likely to require additional decontamination processes and equipment deployed forces must be structured to provide this capability, in addition to "normal" decontamination capacity.

Training – Units or troops assigned to carry out the role of Sensitive Equipment decontamination must be trained and practised in carrying out this task. In addition, they must be trained to identify those systems that can and cannot be decontaminated by "normal" decontamination.

Material – As already mentioned, AEP-7 directs the hardening of military equipment. This requirement should be enforced wherever possible. If this is not possible then other options should include:

- Use of strippable coatings (protection).
- Redundancy of assets – Having additional equipment that can be deployed in the place of the contaminated equipment.

Leadership – Commanders at all levels need to be aware of the need to carry out decontamination, as well as the particular needs of Sensitive Equipment decontamination. More significantly, the impact of loss of mission-critical equipment through CBRN contamination needs to be an integral part of their education in operating in a CBRN environment. Commanders should consider the impact of any CBRN incidents on the

conduct of the mission. Such considerations should be balancing the need to complete the mission or task with the degree or extent of exposure to contamination of their own forces. Commanders at the planning stage should be able to articulate the priorities for decontamination. In particular, mission-critical Sensitive Equipment must be identified. This priority list will need to be reviewed as the operational situation develops. Where it is not possible to decontaminate mission-critical systems, additional numbers of these systems will need to be held. Commanders should be aware of the logistical impacts of having availability of assets through redundancy[3].The rehabilitation of force elements, including manpower and equipment, should be planned for in the event of a CBRN incident. This will include the allocation of decontamination assets and manpower to run the decontamination site(s). As part of the planning process, Commanders should utilise the planning guidance given in A MedP-8 for the calculation of CBRN casualties[4]. This provides useful planning guidelines as to the scale of any decontamination process that may be required. CBRN Staff Officers will play a key role in helping formulate the overall operational plan of how to conduct operations in a CBRN environment. Planning and CBRN knowledge by formation staffs should reduce the impact CBRN incidents on the successful completion of the mission/task.

Personnel – Whereas "normal" decontamination can be carried out by generalist troops, Sensitive Equipment decontamination is likely to require specialist equipment and procedures. Personnel carrying out this task should, therefore, have additional training in this role and have a higher level of CBRN knowledge and education. It is ideally a role for the CBRN Specialist.

Facilities – Sensitive Equipment decontamination is likely to require special equipment and procedures. In many operations, this equipment will need to be portable to enable it to be deployed to the theatre of operation and moved in order to support the mission as it develops. More static facilities may be set up at 3rd Line, at the Airport of Disembarkation (APOD) or Sea Port of Disembarkation (SPOD). In such cases, care must be taken to ensure that any Sensitive Equipment that has been contaminated is contained to minimise the spread of contamination.

Interoperability – The equipment and TTPs used to conduct Sensitive Equipment decontamination should conform to NATO standards, policy and doctrine to allow interoperability within any NATO deployed force. Interoperability with Host Nation infrastructure and capabilities is desirable, but will be mission-specific.

2.4 LINKS TO CBRN DEFENCE-ENABLING COMPONENTS

Detection, Identification and Monitoring – This area is vital to Sensitive Equipment decontamination. Not only will it detect the contamination, but will also be used to verify the efficiency of the decontamination process. It may also warn of approaching CBRN hazards.

Information Management – Although the process of Sensitive Equipment decontamination may not have any Information Management requirements itself, the regeneration of mission-essential capabilities will be information that will be vital to the operational Commanders planning process and overall situational awareness. As a result, the reports and returns on the progress of Sensitive Equipment decontamination will be required, in an agreed format and passed via the operational Communication and Information System (CIS). The timely passage CBRN warning and reporting information can also be used to take action to avoid the Sensitive Equipment becoming contaminated.

Physical Protection – Although hardening and survivability fall under the auspices of Hazard Management, physical protection still has a key role in the Sensitive Equipment decontamination. Measures can be carried out to protect key equipment. Personnel carrying out the Sensitive Equipment decontamination will require

[3] Redundancy – The inclusion of duplicate or alternate system elements to improve operational reliability by ensuring continued operation in the event that a primary element fails (NTMS).

[4] As well as AJMedp-7(A) Allied Joint Medical Doctrine for Sp to CBRN Defensive Operations.

to be protected against CBRN agents when carrying out the process as well as from the waste generated from the process.

2.5 SUMMARY

Sensitive Equipment decontamination is a process to allow equipment, including mission-critical equipment that will be damaged by conventional decontamination procedures, to be regenerated. NATO Nations should ensure that military equipment has hardening, survivability, decontaminability and compatibility incorporated into the design. Where this is not carried out procedures and resources for Sensitive Equipment decontamination will be required. In addition, Commanders and their staff must be cognisant with the appropriate decontamination processes and their implications, particularly in terms of time and resources, in order to plan for either conducting rehabilitation of mission-critical assets or by their replacement.

Chapter 3 – TECHNICAL PART

3.1 BIOLOGICAL DECONTAMINATION

3.1.1 Biological Organisms

Microorganisms can be found throughout our environment. Human beings, animals and plants are continuously exposed to microorganisms, but the majority cannot penetrate the natural defence mechanisms. A small number of bacteria and viruses have properties that allow them to enter hosts, where they can multiply and cause disease. Among these pathogenic microorganisms, there are a number of bacteria and viruses that possess such properties that make them interesting for use as biological weapons.

It is exceptionally difficult to identify an attack from biological microorganisms. The effect is not immediate and the first indication of an attack would probably be a large number of cases of illness or an unexpected disease pattern. It can be difficult to distinguish natural epidemics from intentional spreading. Some microorganisms have very low infectious doses and can easily be transmitted from the primary infected and cause secondary infection which can lead to epidemics. In general, bacterial infections can be treated with antibiotics, whereas active anti-viral substances are still uncommon. Protection against certain types of biological agents can be obtained by vaccination or medication.

Detection is the unspecific demonstration of increased concentrations of microorganisms. It can have two basic aims depending on the timeframe in which it can be carried out:

- "Detect to Warn" – Discovery of the hazard in time to allow a timely adoption of protective measures; or
- "Detect to Treat" – Discovery of the hazard right after its arrival to allow quick implementation of medical countermeasures as well as to limit further exposure by adoption of protective measures.

Identification, on the other hand, is the species determination of microorganisms. It has the purpose to characterize, analyze and determine the nature of the substance of species in quantity and quality in order to confirm the type and nature of the hazard. This will enable further refinement of medical countermeasures, assist in judging the risk of secondary infection and allow better tailoring of measures to handle the outbreak. It is also important to continue monitoring the event in order to eventually confirm the absence of the hazard.

3.1.1.1 Viruses

Viruses are the simplest type of microorganisms. They are in most cases made up of chromosomes with a surrounding cover of protein. Viruses vary in size from 0.02 to 0.2 µm, much smaller than bacteria. Viruses do not reproduce on their own, but are dependent on their host cell. They grow inside the host cell. A virus normally changes the host cell in such a way that the host dies. This property makes viruses pathogenic. Some viruses give local infections at the point of entry. Other can spread to various parts of the body by means of the lymph and blood circulation where they give infections in specific organs or general symptoms.

3.1.1.2 Bacteria

Bacteria are unicellular. They are the smallest living organisms that can reproduce by themselves. Their shape and size varies from rod-shaped organisms that may be several tens of µm long to spherical cocci with a diameter of ca. 0.5 mm. In addition to chromosomal DNA, many pathogenic bacteria also possess plasmids. These are circular DNA structures that frequently carry information on properties involved in the infection process. Under certain unfavorable conditions some types of bacteria can be transformed into spores. The spore of the bacterial cell can be extremely resistant to cold, heat, drought, chemicals and

radiation. The spore can survive for long periods, waiting for favorable conditions to germinate and the bacteria to enter a normal growth phase.

Bacteria can cause diseases in human beings and animals by two different mechanisms by invading tissues or by producing poisonous products, toxins.

Several hundred bacterial toxins have been described, including the most toxic substance known to science. Some pathogenic bacteria possess both properties. It is interesting to note that even if the bacterium that produces a toxin is destroyed, the toxin might be stable, giving rise to effects. Toxins are normally decontaminated using the same methods as for chemical decontamination and will therefore not be discussed.

3.1.1.3 Rickettsia

Rickettsia are a unique type of bacteria and are unable to multiply outside their host cells. In cases of infection, they penetrate into the host cells and utilize them for their reproduction.

3.1.1.4 Fungi

Fungi are larger than bacteria. They grow either as monocells or as multi-cellular thread-like structures. Under unfavorable conditions most fungi develop spores. Some fungi produce stable, extremely toxic toxins.

3.1.1.5 Routes of Infection

Pathogenic microorganisms are transferred to human beings largely via air and food (including water). They penetrate the body through the airways, the gastro-intestinal tract or other mucous membranes. Other routes of infection are by the urinary tracts, the sexual organs and the eyes. In addition, microorganisms may enter the body through wounds and insect bites.

3.1.2 Biological Decontamination

Biological decontamination involves combating various microorganisms to prevent the spread of infection.

Biological decontamination can be carried out at different levels. Sterilization destroys all reproducible life. Disinfection destroys undesirable microorganisms to such an extent that there is no risk of infection. Decontamination is the removal, but not necessarily the destruction of, undesirable microorganisms to such an extent that the risk of infection is eliminated. Although microorganisms can be rendered harmless, one is often forced to discard the most efficient routes, i.e., those that provide complete sterilization, in order to prevent damage to people or to the materials to be decontaminated. When considering decontamination, an important property of the microorganism to take into account is its ability to withstand external influences, to survive in the environment. Many organisms are killed by the sun’s ultraviolet rays or by dehydration. Such natural killing, often up to 50% within 30 minutes, makes additional decontamination unnecessary. Spore-forming microorganisms, having very high survivability, cannot be decontaminated without great disruptive effects. Non-spore-forming microorganisms can, however, be decontaminated using various methods without too much impact on the surroundings or the material to be decontaminated.

It should be noted that there is a lack of standardized protocols for verification of efficiencies in decontamination of microorganism. The view seems to be that if spores like Anthrax endospores are killed by a method, it is likely that a sufficient killing rate can also be achieved for other biological agents.

A score of different decontamination methods exist. In general these can be divided into physical and chemical technologies.

3.1.2.1 Physical B-Decontamination Methods

Mechanical decontamination, being the most elementary form of physical decontamination, removes but does not necessarily kill a microorganism. Washing and cleaning can be sufficient and at the same time often have the advantage of eliminating pollutants that protects the microorganism from the effects of chemical decontamination methods. The filtration of drinking water is a mechanical decontamination method.

As stated, microorganisms are sensitive to heat and radiation. The effectiveness of heat treatment will depend on the relative humidity. To completely inactivate microorganisms in dry heat, two hours of treatment at 160°C is needed. The use of hot water vapor at 121°C and an overpressure of 1 atmosphere reduce the treatment time to 20 minutes. This is autoclaving, and is performed in special apparatuses.

Many materials can be boiled in water. With the exception of sporulating fungi, and a few viruses, microorganisms are destroyed by 15 minutes of boiling.

As previously noted, the sun's ultraviolet radiation has a certain disinfecting effect, often in combination with dehydration.

UV, high-energy electron beams, X-ray and gamma-ray irradiation systems are commercially used for treatment and sterilization. Cost, efficiency, immobility, electric power requirement, toxic waste, personal hazard and time required prevent the use of these for military purposes.

The only really interesting "new" technology for bio-decontamination is "Cold Atmospheric Plasma", which seems to have a great potential.

3.1.2.2 Chemical B-Decontamination Methods

A chemical disinfectant not only removes, it also incapacitates microorganisms. The decontamination agent may be applied as a gas, liquid or aerosol. The effect is dependent not only of the agent itself, but also of the concentration used and by factors such as temperature and pH. Many of the chemical substances used are harmful to humans, animals and materials. Because of this, the benefits must be weighed against the **disadvantages** before deciding to use a specific agent. In Appendix 2, some examples of the efficacy of different chemical decontamination agents on various microorganisms are given. It should be noted that even if the available decontamination agent is not expected to yield a satisfactory result, it is better to implement a (flawed) decontamination than none at all.

Typical contact times needed to decontaminate spores is 2 – 4 hours, for viruses 5 –60 minutes and for bacteria and rickettsia 2 – 10 minutes.

Recent results question the efficacy of decontamination of spores. These seem to be much harder to decontaminate than has been previously anticipated.

3.1.2.3 Summing Up

A number of factors affect the efficiency of biological decontamination. Among these are the organism, its survivability, the amount, type of surface contaminated, decontaminant, method of decontamination, organic co-contaminants, temperature, humidity as well as other environmental factors. These need to be taken into account when judging the applicability and efficiency of a decontamination methodology. The development of protocols combining several biological decontamination methods is recommended.

The lack of standardized protocols for verification of efficiencies in decontamination of microorganism is troubling. There also seems to be a large lack of pertinent experimental data on the efficiencies of different methods in reducing the large number of different bio-organisms of interest.

Most methods/systems described adhere to "classical" ways of decontamination like washing, mechanical treatment (wipe), the effects of different chemicals, weathering at elevated temperatures. There are some tweaks; vacuum, vaporized chemicals, steam. A number of different biological decontamination methods utilize different basic types of disinfectant processes. In order to be applicable to Sensitive Equipment decontamination, the equipment has to withstand the method specifics. These are normally:

- Elevated temperatures;
- Elevated temperatures with steam;
- Washing with different types of liquids and water;
- Mechanical wipes with powders; and
- Different types of oxidative solutions and vapors.

3.2 CHEMICAL DECONTAMINATION

3.2.1 Introduction

Chemical Warfare Agents (CWAs) are chemical substances which can be used to kill, seriously injure or incapacitate people through their physiological effects. They can be classified as nerve agents (G- and V-types), vesicants, cyanogen (blood) agents, lung damaging (choking) agents and Toxic Industrial Chemicals (TICs). They can exist as a vapour, a solid or liquid aerosol, or slowly evaporating liquid droplets. Some agents are non-persistent (e.g., sarin), meaning that they have a high volatility, and primarily necessitates protective measures like Individual Protective Equipment (IPE). Other agents are considered persistent (e.g., sulphur mustard and VX), meaning that they have a low volatility, and necessitates the need for decontamination. CWAs in vapour form can penetrate into the interior of equipment and damage the equipment if the agents are highly corrosive. CWAs in aerosol or liquid state can adhere to a surface, spread over the surface and penetrate into capillary spaces (e.g., cracks and crevices, joints and screw threads). Some agents can also be absorbed into permeable and porous materials of equipment, such as rubbers, plastic and paints, due to their solvating powers. Such absorption can cause changes to the properties of these materials which in turn can affect the proper function of the equipment. All surfaces contaminated with CWAs are associated with different levels of contact hazards as well as inhalation hazards due to agents evaporating. The levels of hazards are dependent amongst others on type and form of agent, contamination density and persistency, surface properties like roughness and permeability. These hazards can be reduced by doing decontamination.

Decontamination is a process of making any person, object or area safe by absorbing, destroying, neutralizing, making harmless or removing in this case CWAs. It is an essential part of CBRN defence, along with avoidance and protection. Decontamination can be divided into two categories:

- Passive; and
- Active.

Passive decontamination is done by exposing an object to high temperature, sunlight and wind (weathering). This is a very time-consuming process. Be aware of the possible (re)aerosolization the wind can do with particular CWAs. Passive decontamination can also include the pre-treatment of different surfaces with protective layers or reactive coatings that can be removed or destroy the CWAs faster than normal weathering (see Section 3.4.2.1). Active decontamination is a process of removing or neutralising liquid or solid contamination of CWAs. It should be done as quickly as possible and decontamination of personnel should take priority over equipment and terrain. Detection, identification and monitoring devices are used to separate contaminated from uncontaminated and provide a measure of efficiency of decontamination as far as reasonably possible. Active decontamination is divided into three levels:

- Immediate;
- Operational; and
- Thorough.

Immediate decontamination is done by the individuals and may include the decontamination of personal clothing and/or equipment. It is done to save lives, minimize casualties and limit the spread of contamination. Immediate decontamination can also be done on IPE to sustain personal protection. Operational decontamination is done by an individual and/or a unit on specific parts of operational significant equipment. It is done to minimize the contact and transfer hazard and to sustain operations. As a minimum, contact area of weapons and equipment are decontaminated to restore immediate combat effectiveness. Thorough decontamination is done by a unit to reduce contamination on personnel, equipment, materiel and/or working areas to lowest possible levels. It is done to do partial or total removal of the IPE and maintain operations with a minimum of disadvantage. However, there is a challenge to verify the achievement of the different levels of decontamination. Detection and monitoring devices can be insufficient for such verification. Other measures like reach back laboratory analysis may be needed to assess the contact, inhalation and residual hazard related to the performed decontamination.

Active decontamination can be divided into three basic processes:

- Physical;
- Chemical; and
- Biochemical.

Physical decontamination methods aim to remove or encapsulate the CWAs to reduce their dangerous properties of exposure. It is looked upon as partial decontamination since the CWAs are only just relocated but still remain a hazard. Examples of physical decontamination methods are:

- Rinsing with water;
- Rinsing with organic solvents and mixtures;
- Washing/rinsing with surfactants;
- Accelerated evaporation by heating (optionally combined with vacuum techniques);
- Adsorption and removal with solid adsorbents (e.g., Fuller's earth);
- Removal of protective layers applied prior to contamination;
- Burying or sealing contamination;
- Scrubbing with brush or abrasive material; and
- Vacuum cleaning.

Chemical decontamination methods aim at modifying the chemical structure of the CWAs to reduce or completely eliminate their toxicity or ease their removal. This is mainly done by chemical reactions using the principle mechanisms of hydrolysis or oxidation. Irradiation with Ultraviolet (UV) light, the use of plasma and thermal treatment are also looked upon as methods of chemical decontamination. There is one or any combination of the three processes involved during chemical decontamination:

- Electrophilic (oxidation or chlorination);
- Nucleophilic (hydrolysis or other nucleophilic attack); and
- Complete destruction (full oxidation, thermal degradation, plasma-induced radical reactions).

Biochemical decontamination methods are the use of agent-scavengers or enzymes to catalyse specific degradation reactions. Enzymes are very selective and exhibit multiple turnover possibilities as opposed to chemical reactants which are being consumed in each reaction. They are also compatible with the environment. Examples of enzymes in use are:

- Organophosphorous Acid Anhydrolase (OPAA);
- Organophosphorous Hydrolase (OPH); and
- Diisopropylfluorophosphatase (DFPase).

Active decontamination can be a combination of the three basic possesses (physical, chemical and biochemical) described above to get an optimal degree of decontamination. Waste management will also have to be taken into account when doing decontamination.

Sensitive equipment decontamination is related to the items that cannot be decontaminated by the commonly used methods described above (e.g., rinse with water or by using chemically reactive decontaminants). Such decontamination will cause damage to the items or lead to a degradation of their performance. Some CWAs may also cause damage to these sensitive items. Sensitive equipment can be special items of personal equipment as well as material and equipment critical for an operation or to perform a mission. Examples of Sensitive Equipment can be:

- Computers and electronics;
- Optical devices; or
- Flight critical components within or on an aircraft.

Decontamination of Sensitive Equipment can mean the use of one or a combination of different decontamination technologies described hereinafter.

3.3 RADIOLOGICAL/NUCLEAR DECONTAMINATION

3.3.1 Introduction

While chemical or biological decontamination in most cases means that the agents will be destroyed or transformed to less harmful products, radiological contaminations can only be removed from the contaminated surface and cannot be converted to innocuous products.

Therefore many of the procedures proposed for B- and/or C-Decontamination of Sensitive Equipment are not applicable in the radiological case.

The aim of radiological decontamination can only be to remove radioactive particles and/or dissolved radioactive products in order to reduce the dose rate resulting from the contamination on the material, thus reducing the external irradiation hazard, minimize contact hazard and prevent the re-aerosolization of residual particles which may be an inhalation/ingestion issue.

Decontamination procedures for radioactive particles are mainly vacuuming (dry particles, smaller items), swiping or washing/rinsing processes, supported by mechanical means such as high pressure, scrubbing or brushing. Chelating agents will improve the process by forming chemical complexes with radionuclides that are stronger than binding forces to the surface and will also prevent the adhesion of solved nuclides to the surface during the decontamination process. Strippable coatings are either applied prior to engagement to protect the equipment or improve decontaminability, or are applied after the equipment has been contaminated to help collect and remove radioactive particles. In addition, these coatings may also prevent re-aerosolization, thus reducing or avoiding an aerosol hazard.

3.3.2 Types and Properties of Contaminations

The efficiency of decontamination and the procedures used depend strongly on the chemical and physical properties of the contaminant. Radiological material can come in different chemical and physical form as well as a variety of isotopes.

Radioactive contaminations from nuclear fallout vary distinctly from those arising from Radiological Dispersion Devices (RDDs) or nuclear reactor failures (either accidental or intentional).

Nuclear fallout includes of a wide spectrum of different nuclides (fission products). Although there are also some soluble compounds (“rainout”), fallout is considered to consist mostly of insoluble larger (> 50 µm) particles.

Particles from RDDs may range from larger particles/debris close to the explosion area to particles down to micron and sub-micron size at further distances. Their solubility depends on the isotope and the properties of the radioactive source. Particle size and solubility impact the effectiveness of decontamination operations. With regard to Sensitive Equipment decontamination, especially fine particles (soluble or insoluble) have to be considered because these are most likely to get in contact with the material, stick to it or even penetrate into gaps or surface structures.

The application of a decontamination solution may not be feasible for all radiological material. The following table lists the most common isotopes typically used in radioactive sources with a wide range of chemical forms ranging from salt, oxide, metal to ceramic matrices.

Used in an RDD, these nuclides and their chemical or physical form define the properties of the resulting contamination and the efficiency of decontamination procedures.

Table 3-1: Radiation Sources for the Potential Use in a RDD [1].

Radionuclide	***Form***
Americium-241	Americium oxide; Americium-Beryllium (AmBe) neutron sources are typically compressed powders
Californium-252	Californium oxide
Cesium-137	Cesium chloride
Cobalt-60	Metallic cobalt, or cobalt-nickel alloy
Iridium-192	Metallic iridium
Plutonium-238	Plutonium dioxide, generally pressed into a ceramic-like material
Polonium-210	Metallic foil
Radium-226	Radium bromide or radium chloride
Strontium-90	Metallic strontium, strontium chloride, strontium-fluoride, strontium-titanate

Especially widely used, soluble compounds like Cesium or Strontium Chloride must be highlighted as most hazardous sources because these compounds can be easily spread and decontamination is difficult due to particle size and solubility.

A well-reported incident happened in Goiania/Brasil in 1987 when a Cs-137 source from a radiotherapy device containing CsCl had been dismantled by unskilled persons, who took the material home and showed

or gave the material to other people. Four fatalities and a number of casualties happened due to radiation and many houses and outside areas were contaminated [2].

3.3.3 Classification of Contaminations

According their properties, contaminations can be classified in different categories. Not every decontamination procedure proposed will work efficiently for all types of contamination:

- Liquid contamination: Nuclides dissolved in water, dried on a surface.
- Soluble particles:
  - 2.a. dry.
  - 2.b. under humid conditions.
- Insoluble Particles:
  - 3.a. size > 10 µm.
  - 3.b. size < 10 µm.

In the technologies descriptions, the applicability and the efficiency is rated according to these types of contamination. A technology that can, for example, be used for the thorough decontamination for insoluble particles may be not or only limitedly usable for contaminations solved in water.

3.3.4 Levels of Decontamination

The levels of activity and the resulting dose rates in nuclear scenarios can be expected to be much higher than those of radiological contaminations. However, the limits for thorough nuclear decontamination as defined in AEP-58, Annex G (STANAG 4653) are orders-of-magnitudes greater than those given in the STANAG 2473 (withdrawn) and by civil legislation. Thorough decontamination of insoluble nuclear fallout particles is quite easy to achieve. The diversity in the chemical and physical properties of radiological contamination and the low limits to be achieved for residual contamination make radiological decontamination much more demanding. Although the basic principle and procedures of decontamination are the same, radiological decontamination may require efforts that go beyond the standard military decontamination procedures. This could include the need for more time, more personnel, adapted techniques and equipment or specified decontaminants.

For radiological decontamination, the advantage in evaluating a decontamination process and the remaining hazard after decontamination lies in the very sensitive and easy to handle detection equipment available, which allows direct on-site measurement.

Contaminated Sensitive Equipment may be measured before and after the decontamination process to determine the efficiency of contamination removal. Thus the remaining hazard can be rated in order to determine if the result of the decontamination is sufficient or not. Decisions can be taken whether the equipment can be released for further use, needs further decontamination or probably has to be withdrawn from application, stored or declared as radioactive waste.

3.4 DECONTAMINATION TECHNOLOGIES FOR SENSITIVE EQUIPMENT DECONTAMINATION

This section describes in detail the different current and future systems and technologies that can be used for Sensitive Equipment decontamination. Most of the systems on the market and technologies available to the user deal with two or more different types of contamination.

3.4.1 Current Technologies

3.4.1.1 Absorptive Technologies [3], [4], [5]

High-absorptive technologies can be used for contamination removal. This principle is mainly used for immediate decontamination of the skin and operational decontamination of small equipment on soldiers (clothes, electronics, weapons, etc.). These products have the advantage to be highly compatible with different materials. Different absorbents (physical decontamination) are described below.

3.4.1.1.1 Powder Glove

Capable of treating complex surfaces and cover large surface areas, but can be in some cases pulverulent and induce a re-aerosolization hazard. An example of a commercial system is the powder glove where one side of the glove stocks absorbing powder (Fuller’s earth). The powder is patted onto the contaminated surface and the other side, made with sponge tissue, allows removal of the powder containing the liquid contamination absorbed.

Although, due its underlying technical principal, this technology also seems suitable for R/N contamination removal, it is nearly exclusively used for C-decontamination.

Basic Technical Principle:	Physical removal (absorption).
Usable for Level of Decontamination:	Immediate, Operational.
Countries of Use:	France.

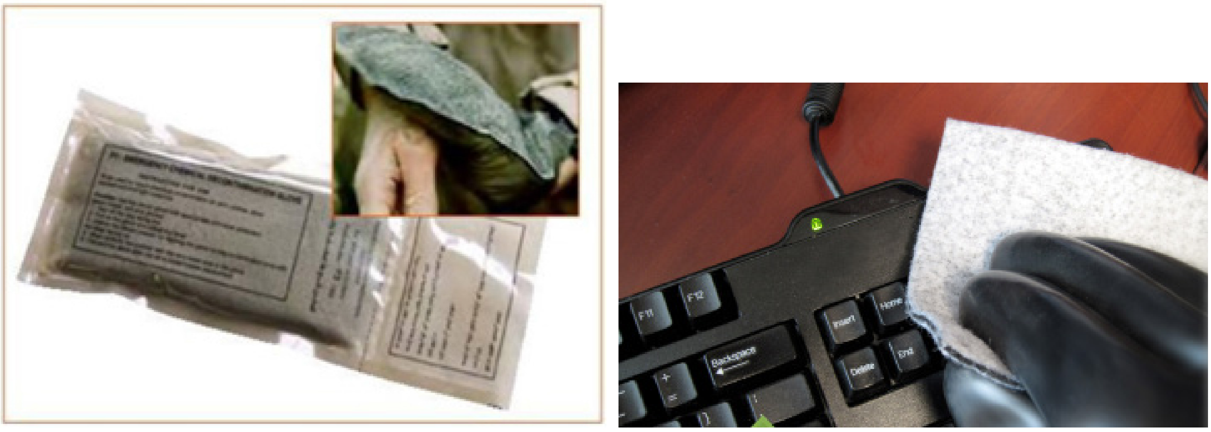

Figure 3-1: Powder Glove (www.nexter-group.fr).

3.4.1.1.2 Dry Fiber Wipe

Accessibility of surfaces and surface covered are often lower than with powder; however, wipes have advantages to limit aerosolization hazard. Example of this system is the dry fiber wipe developed in the USA.

Basic Technical Principle:	Physical removal (absorption).
Usable for Level of Decontamination:	Immediate, Operational.
Countries of Use:	United States.

Figure 3-2: Fibertect Wipe (http://advancedtextilessource.com).

Table 3-2: Technology Characteristics for the Powder Glove and the Dry Fiber Wipe.

N°- Requirement	Technical Specifications
Mobility	Self-contained in packaging, potentially part of the individual equipment of the soldier.
Set-up time / Strike time	< 1 minute.
Capability (efficacy, capacity)	Potential removal of bulk contamination (limited efficacy on B/R/N). May require multiple applications (wipes). Potential for cross-contamination.
Compatibility (other NATO decontaminants)	Compatible with almost all materials, other decontaminant procedures.
Interoperability	Stand-alone packages.
Support and logistics	Self-contained, operable by a single personnel in PPE. No power supply required, low logistical footprint, and may require physical exertion for extended application
Environmental aspects	Requires collection and treatment of wipe and glove. The powder glove contains fuller's earth which is a natural substance, highly compatible with the environment.
Operational parameters	Minimal application time.
Shelf-life parameters	Long shelf life (> 10 years).
Training	Minimal, training in application and proper PPE use.
Compatibility with forensic processes	Incompatible with forensic processes like footprint conservation.

3.4.1.1.3 Evaluation of the Technology

This absorptive technology is usable for chemical, biological and radiological contamination in a liquid form, but gives no degradation of the contamination.

Advantages:

- Inert powder;
- Readily available / easy to use;
- Compatible with most materials;
- Targeted application;
- Low logistical burden; and
- Long shelf life.

Drawbacks:

- Limited surface to decontaminate;
- Potential for hazardous re-aerosolization;
- Only for bulk liquid contamination;
- Less active for complex surface structures;
- Potential for cross-contamination;
- May need treatment after use;
- May need more physical exertion; and
- May require multiple applications.

Table 3-3: DOTMLPF-I Rating for Powder Glove and the Dry Fiber Wipes.

Doctrine	
Organization	-
Training	-
Materiel	+
Leadership	-
Personnel	-
Facilities	-
Interoperability	

There are also other systems existing, associated with vacuum engines, to suck up the contaminated powder. These systems are mainly used for thorough decontamination.

Table 3-4: DOTMLPF-I Rating for Other Existing Systems.

Doctrine	
Organization	-
Training	+
Materiel	+
Leadership	-
Personnel	-
Facilities	-
Interoperability	

3.4.1.2 Adsorption on Microfiber Fabrics (Wipes)

Microfiber fabrics have high adsorption ability due to the enlarged “active” surface. This improves significantly the removal of particles and liquids.

A microfiber fabric is a textile composed of extremely fine threads, usually manufactured from a mixture of polyester and polyamide. The resulting textile is highly absorbent, and has properties that strongly attract dust particles based on electrostatic entrapment of dust particles in the tiny microfibers. The fibers can get into cracks and crevices too small for other materials. The cloths can be used dry or moistened with water only, i.e., surfaces are cleaned without the use of chemicals.

Basic Technical Principle:	Adsorption in fibre structure
Usable for Level of Decontamination:	Operational
Countries of Use:	Germany.

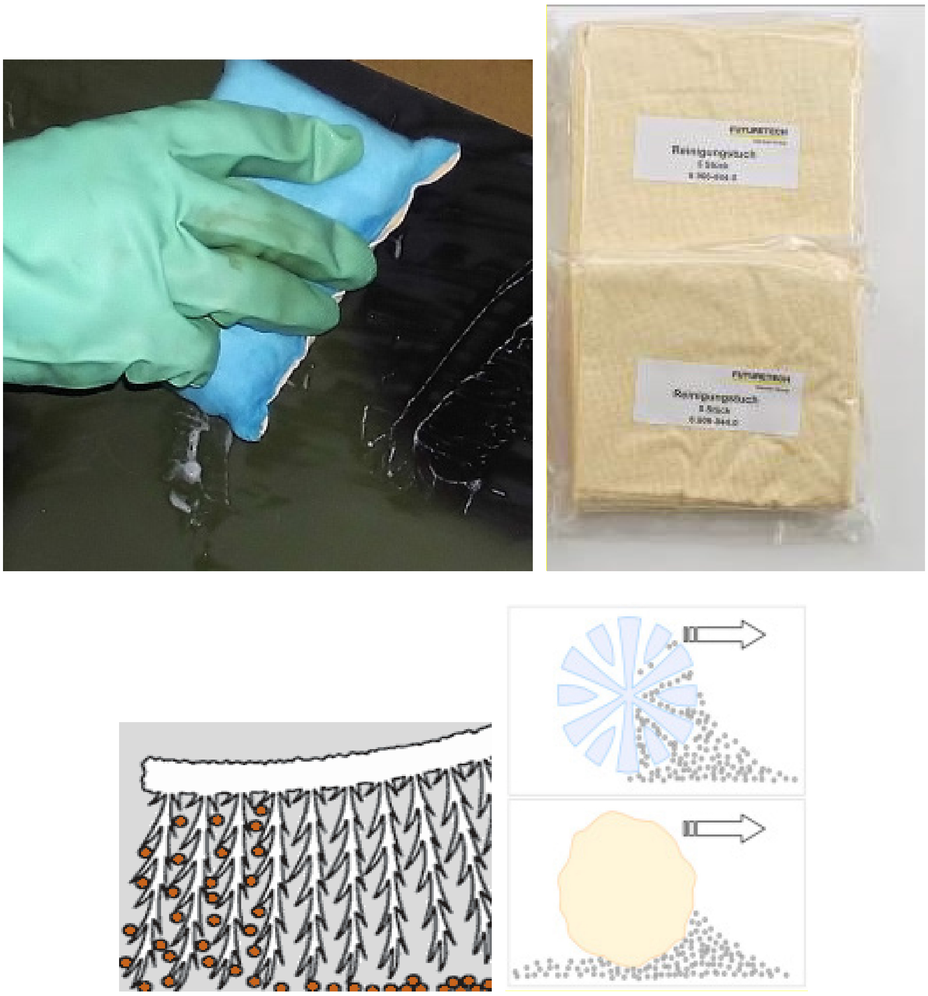

Figure 3-3: Example of Microfiber Wipes (www.rekashop.de).

Table 3-5: Technology Characteristics for Microfiber Fabric.

N°- Requirement	Technical Specifications
Mobility	Self-contained in packaging, potentially readily available on war fighter.
Set-up time / Strike time	< 5 minutes.
Capability (efficacy, capacity)	Removal of surface contamination, application dry or moistened, may require multiple applications, potential for cross-contamination.
Compatibility (other NATO decontaminants)	Compatible with virtually all materials, other decontaminant procedures.
Interoperability	Stand-alone packages.
Support and logistics	Self-contained, operable by a single personnel in IPE. No power supply required, low logistical footprint, may require physical exertion for extended application.
Environmental aspects	Requires collection and treatment of wipes.
Operational parameters	Minimal application time.
Shelf-life parameters	Long shelf life (> 10 years).
Training	Minimal, training in application and proper IPE use.
Compatibility with forensic processes	Incompatible with forensic processes.

3.4.1.2.1 Evaluation of the Technology

Chemical Decontamination:

This system allows for chemical decontamination removal due to the high absorptive properties of microfibers. This system is usable for operational decontamination of small equipment or surfaces.

Biological Decontamination:

This is a system for the mechanical removal of a contamination. Hence, as a stand-alone it is not suitable for biological decontamination.

R/N-Decontamination:

It is usable for R/N contaminations Category 1, 2 and 3 up to level “operational”, for 2.a and 3.a thorough level can be reached depending on the contaminated surface.

Advantages and Application Properties:

- Wide range of application;
- Dry method (or only moistened cloth);
- Usable for all types of radiological contamination with advantage for particulate contamination;
- Cleaning / dirt removal ability;
- Easy to handle;
- Simple method for operational decontamination; and
- Cheap, many COTS products available.

Drawbacks:

- Mainly operational application only;
- May not be effective on complex surfaces; and
- Efficacy limited for dirty or greasy surfaces.

Table 3-6: DOTMLPF-I Rating for Microfiber Fabrics (Wipes).

Doctrine	
Organization	
Training	+
Materiel	+
Leadership	
Personnel	
Facilities	
Interoperability	+

3.4.1.3 Solvent Mediated Fiber Wipes [6]

To allow immediate decontamination and be readily available to the soldiers, the United States has developed solvent-mediated fiber wipes, which combines the solubilisation effect of a solvent and the absorptive properties of a wipe (physical decontamination). This wipe is compatible with Sensitive Equipment carried by the soldiers.

Basic Technical Principle:	Physical removal.
Usable for Level of Decontamination:	Immediate.
Countries of Use:	United States.

Figure 3-4: Solvent-Mediated Fiber Wipe (ECBC).

Table 3-7: Technology Characteristics for the Solvent-Mediated Fiber Wipe.

N°- Requirement	Technical Specifications
Mobility	Self-contained in packaging. Part of the individual equipment for the soldiers.
Set-up time / Strike time	< 5 minutes.
Capability (efficacy, capacity)	Potential removal of bulk contamination of CB. May require multiple applications. Potential for cross-contamination. Unknown efficacy for RN.
Compatibility (other NATO decontaminants)	Compatibility will depend on solvent contained in wipe. Compatible with other decontaminant procedures.
Interoperability	Stand-alone packages.
Support and logistics	Self-contained. Operable by a single personnel in PPE. No power supply required. Low logistical footprint. May require physical exertion for extended application.
Environmental aspects	Requires collection and treatment of wipe.
Operational parameters	Minimal application time.
Shelf-life parameters	Long shelf life (> 10 years).
Training	Minimal, training in application and proper PPE use.
Compatibility with forensic processes	Probably incompatible.

3.4.1.3.1 Evaluation of the Technology

This technology can be used on chemical, biological and radiological contamination by solubilizing and/or absorbing the contamination.

Advantages:

- Less aggressive than other decontaminants;
- Low cost and logistical footprint;
- Compatible with most materials;
- Targeted application and dual use when it comes to cleaning; and
- Long shelf life.

Drawbacks:

- No degradation;
- Not compatible with electronics;
- Requires treatment after use or be declared as waste due to residual hazards;
- Manual process which may need more exertion/applications; and
- Long process with limited efficacy on complex features/highly absorptive materials.

Table 3-8: DOTMLPF-I Rating for Solvent Mediated Fiber Wipe.

Doctrine	
Organization	-
Training	-
Materiel	+
Leadership	-
Personnel	-
Facilities	-
Interoperability	

3.4.1.4 Manual Washing with Water and Surfactants

For equipment sensitive to highly corrosive decontamination solutions, chemical contamination can be removed by washing with non-aggressive solvents or surfactants provided the chemical contaminations are highly soluble in the solvent/surfactant of chose (physical decontamination).

This is a standard manual cleaning procedure; it can be supported by mechanical work like swiping or brushing. Contaminants are detached from the surface and subsequently rinsed or washed away.

It can be used for all categories of contamination, the efficacy of the method depending on the type of contamination (solubility, particle size) and the properties of the surface material and structure. Operational decontamination will be reached at any rate, thorough depends on conditions.

In the case of fallout decontamination, the addition of a chelating agent like EDTA or Citric Acid improves decontamination efficiency significantly.

Specific decontaminants on this basis (RDS 2000) have been tested successfully on non-hardened electronic equipment (test object Raspberry Pi; DEU, CAN 2015).

Basic Technical Principle:	Physical removal.
Usable for Level of Decontamination:	Operational, Thorough.
Countries of Use:	Due to the simplicity, of the technology, nearly all countries, worldwide.

Table 3-9: Technology Characteristics for Washing with Water and Surfactants.

N°- Requirement	Technical Specifications
Mobility	Highly mobile to limited mobility depending on system size.
Set-up time / Strike time	Less than 15 minutes.
Capability (efficacy, capacity)	Operational and – under certain conditions – thorough R/N decontamination; operational C- and B-decontamination potential for elevated efficacy on impermeable materials. Limited efficacy on absorptive substrates.

N°- Requirement	Technical Specifications
Compatibility (other NATO decontaminants)	Different commercially available surfactants. Specific formulations as COTS Decontaminants available.
Interoperability	As stand-alone system.
Support and logistics	Water and chemicals have to be provided. Tubs, racks and swiping/brushing equipment.
Environmental aspects	Waste collection/treatment has to be taken into account at the end of operations.
Operational parameters	Typical application times ~15 to 30 minutes. Elevated efficacy anticipated for wide environmental temperature range.
Shelf-life parameters	Most of surfactants have long shelf life (> 5 years).
Training	Low burden, training for decontamination mixing, application procedures, PPE requirements.
Compatibility with forensic processes	Incompatible with forensic processes.

3.4.1.4.1 Evaluation of the Technology

Chemical Decontamination:

Chemical decontamination is achieved by mechanical removal of contamination. The rate of solvents or surfactants into the solution has to be carefully chosen in function of their solubilisation (for solvent), emulsification (for surfactant) properties and compatibility with the equipment to decontaminate. In this process, the mechanical effect is predominant for decontamination efficiency and on non-absorptive material; it is possible to reach up to thorough level of decontamination.

Biological Decontamination:

The method is described as a standard manual cleaning procedure. By a suitable choice of decontamination solution disinfection or even sterilization might be achieved in combination with mechanical removal. The decontaminant and/or the concentration of the active substance used can be chosen to be compatible to different types of Sensitive Equipment. The choice of decontaminant and the strength used will affect the efficiency of reduction of bio-organisms. This will most probably result in the need for longer treatment times, the need to carry out the process in several cycles or to combine the technology with another type of decontamination technology.

R/N-Decontamination:

This is a standard manual procedures that should be available in most countries even though the applied detergents/decontaminants may be different, being applicable for operational or thorough decontamination. The method is not or only limitedly applicable for water sensitive materiel (e.g., “open” electronics), although small computer plates (like Raspberry Pi) have been tested successfully and – after full drying – did work properly.

Advantages:

- Many COTS products available;

- Procedures similar to conventional cleaning;
- Removal of dirt and radioactive particles;
- Less aggressive than other decontaminants; and
- Long shelf life.

Drawbacks:

- Not applicable for liquid-sensitive material; and
- Precautions to collect waste waters.

Table 3-10: DOTMLPF-I Rating for Manual Washing.

Doctrine	
Organization	-
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	+

3.4.1.5 Mild Decontamination Solutions [7], [8], [9], [10], [11]

Sensitive equipment can be decontaminated with mild decontamination solutions. Examples of such mild solutions are the Reactive Skin Decontamination Lotion (RSDL), developed in Canada, and the alldecont, developed in Germany. These are both immediate skin decontamination solutions with active components integrated in their systems. A sponge or a wipe to get the decontamination solution in contact with the contaminants are generally utilized.

RSDL is a Methoxy Polyethylene Glycol (MPEG) based liquid with the content of an active oxime (potassium 2,3-butanedione monooximate) in a sponge. A decontamination solution with a higher content of the oxime in a 500 ml bottle is also available. This is called the Reactive Decontamination Liquid (RDL) and is for use on surfaces and equipment, not on bare skin.

Basic Technical Principle:	Degradation (chemical reaction).
Usable for Level of Decontamination:	Immediate.
Countries of Use:	Canada and Germany.

Figure 3-5: Reactive Skin Decontamination Lotion (RSDL, Left) and Training Version (Right). (www.rsdl.com).

Alldecont is a solution of sodium hypochlorite in water, butyl carbitol and soaps of fatty acids. It is available in personal applicators and in manual sprayers and is used for decontamination of uninjured skin and personal equipment.

Basic Technical Principle:	Degradation (chemical reaction).
Usable for Level of Decontamination:	Immediate, operational.
Countries of Use:	Germany.

Figure 3-6: Alldecont and AlldecontMED (www.cbrnesolution.com).

Table 3-11: Technology Characteristics for the RSDL and Alldecont Systems.

N°- Requirement	Technical Specifications
Mobility	Self-contained in packaging. Potentially part of the individual equipment of the soldier.
Set-up time / Strike time	< 1 minute.
Capability (efficacy, capacity)	Potential removal of bulk contamination. May require multiple applications.
Compatibility (other NATO decontaminants)	Compatible with a lot of materials. Active with a limited contact time and amount of applied solution.
Interoperability	Stand-alone packages.
Support and logistics	Self-contained. Operable by a single personnel in PPE. No power supply required. Low logistical footprint. May require physical exertion for extended applications.
Environmental aspects	Requires collection and treatment of sponge or wipes.
Operational parameters	Minimal application time.
Shelf-life parameters	5 years
Training	Only minimal training effort needed for application and proper use.
Compatibility with forensic processes	Incompatible with forensic processes like footprint conservation.

3.4.1.5.1 Evaluation of the Technology

Both technologies can be used on chemical contamination. The active substances (oxime for RSDL and hypochlorite for Alldecont) allow for degradation of the CWAs. The use of an impregnated sponge or a wipe improves dissolution and gets the active components in contact with the contaminants.

Advantages:

- Readily available;
- Easy to use;
- Compatible with most materials;
- Targeted application;
- Low logistical burden; and
- Long shelf life.

Drawbacks:

- Limited surface area which can be decontaminated;
- Less active for complex surface structures;
- May require multiple applications; and
- Need for waste management.

Table 3-12: DOTMLPF-I Rating for Mild Decontamination Solutions.

Doctrine	
Organization	-
Training	-
Materiel	+
Leadership	-
Personnel	-
Facilities	-
Interoperability	

3.4.1.6 Accelerated Hot Air Weathering

Figure 3-7: Accelerated Hot Air Weathering Systems (United States Air Force Air Mobility Command / A3, 2015).

Table 3-13: Technology Characteristics for the Accelerated Hot Air Weathering System.

N°- Requirement	**Technical Specifications**
Mobility	Mounted in trailers or containers. Requires generator, fans, heat generator.
Set-up time / Strike time	15 to 30 minutes.
Capability (efficacy, capacity)	Potential for thorough C and B decontamination. Decontamination capacity and throughput depends on processing parameters.
Compatibility (other NATO decontaminants)	No active chemistries required for operation. Not applicable for R/N decontamination.
Interoperability	Stand-alone system, but requires scrubber/filtration system on output.
Support and logistics	Needs power supply, filtration system.

N°- Requirement	Technical Specifications
Environmental aspects	No chemicals required, no liquid hazardous waste, requires proper handling of contaminated filters.
Operational parameters	
Shelf-life parameters	> 10 years.
Training	Training in instrument operation. Proper handling of contaminated items. Personal protective equipment required.
Compatibility with forensic processes	

3.4.1.6.1 Evaluation of the Technology

Chemical Decontamination:

In this process, the chemical contaminant evaporates (physical decontamination) at temperatures around 80°C. The process time is agent-type dependent. The system needs no chemicals, is efficient for high volatility contaminants and can be used on complex geometry assets. It typically requires long treatment times (greater than 1 day) and requires the collection and treatment of exhaust and by-products.

Biological Decontamination:

To achieve complete inactivation of bio-organisms in dry air, a temperature of 160°C needs to be maintained for 2 hours. The technology uses a temperature of 80°C and dry air. This will result in low reduction rates that will increase the time needed for treatment. The rates of reduction will be dependent of the organism that is to be treated. If these effects have been studied is not known. Never the less, a reduction of the number of organisms will be achieved which is a step in the right direction. The relatively low temperatures used can be maintained in large structures making it possible to decontaminate large and complex structures. The need to maintain a constant temperature over the whole structure might present a problem.

R/N-Decontamination:

Since this technology does not physically remove the contamination, it is not applicable to R/N-contamination.

Advantages:

- Efficient with high volatility contamination;
- Works on complex geometry assets;
- No chemicals needed; and
- Compatible with most materials except low melting polymers.

Drawbacks:

- Needs treatment of exhaust and process for by-products;
- Not so efficient for low volatility contamination;
- Requires long treatment times; and
- Condensation may occur in cold zones.

Table 3-14: DOTMLPF-I Rating for Accelerated Hot Air Weathering.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	+
Personnel	+
Facilities	+
Interoperability	

3.4.1.7 Dry Aspiration [12]

Particulate contaminations are removed by dry vacuum cleaning, comparable to standard dirt cleaning processes (physical decontamination). It can be applied on all kinds of equipment as well as in the interiors of vehicles and collects the residues on filters. Devices have to be equipped with fine particle filters (HEPA or equivalent) to ensure no aerosolization of breathable particles. It is usable to remove particulate B and C contamination and R/N contaminations categories 2.a and 3.a (see Section 3.3.2), for 2.b and 3.b limited to operational. Nearly no efficacy is achievable for liquid contamination.

One must be aware that when collecting radioactive particles in the device this may lead to a high dose radiation source and the need for protective measures. The system is compatible with all sorts of materials.

Basic Technical Principle:	Physical removal.
Usable for Level of Decontamination:	Operational; R/N: up to thorough in case of non-adherent, particulate contamination.
Countries of Use:	Canada, France and Germany.

Figure 3-8: Dry Aspiration Systems (www.bergin.at; WIS).

Table 3-15: Technology Characteristics for the Dry Aspiration System.

N°- Requirement	Technical Specifications
Mobility	Handy portable devices or mobile wheeled systems of different size.
Set-up time / Strike time	5 minutes.
Capability (efficacy, capacity)	Operational particulate B and R/N decontamination. Particulate TIC. Removal of contamination, only operational, no thorough decontamination.
Compatibility (other NATO decontaminants)	
Interoperability	Stand-alone systems.
Support and logistics	Self-contained, operable by a single person in IPE, needs power supply. Supply of spare filters and dust collection bags required.
Environmental aspects	Consider safety precautions. Particle filters and dust bags present hazards to the operator waste disposal.
Operational parameters	
Shelf-life parameters	> 10 years.
Training	Training in handling and application.
Compatibility with forensic processes	Partly, finger prints not affected, DNA material only partly removable.

3.4.1.7.1 Evaluation of the Technology

This technology can be used for removing particulate chemical, biological and radiological contamination. There is nearly no efficacy to be achieved for liquid types of contamination.

Chemical Decontamination:

During the dry aspiration process no degradation of contamination occurs. Chemical vapour filters are needed to take care of chemical evaporation and all particulate filters need to be managed after use.

Biological Decontamination:

The technology is based on the mechanical reduction of particulate matter. The rate of reduction will be dependent on the size of the particulate matter to be treated. Even if a reduction is achieved, which is a good thing, it is questionable if the reduction will be of a magnitude that will render the object safe to handle. There will be a need to use high-efficiency filters that need to be handled with care and treated to kill the organism in order not to produce secondary contamination. There also seems to be a risk in the technology itself of producing a secondary contamination.

R/N-Decontamination:

During the dry aspiration process no degradation of contamination occurs. Particulate filters need to be used, which will require management after use.

Advantages:

- Many systems COTS available;

- Simple procedure, easy handling;
- Usable with good efficiency for dry radiological contamination, particles and particulate TICs;
- Removes particulate contamination;
- Can be used on all kinds of equipment and materials in different shapes and sizes;
- Instant waste collection on filters; and
- No harmful effects.

Drawbacks:

- No degradation of contamination, hence need of proper waste management;
- Only operational decontamination;
- Ineffective for R/N- contamination cat. 1 (dissolved nuclides);
- Collection of radioactivity in the device must be considered (radiation source); and
- Humidity will affect decontamination efficacy.

Table 3-16: DOTMLPF-I Rating for Dry Aspiration.

Doctrine	
Organization	-
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	+

3.4.1.8 Dual-Step Process Absorption/Vacuuming [13], [14]

This process has been developed by the Italian company Cristanini especially for the C, B and RN decontamination of Sensitive Equipment under the commercial name SX34.

The contaminated material is sprayed with a non-corrosive adsorbent (in pressurized canister). According to the manufacturer, this adsorbent is able to reach all areas of an item, even partly inside or in gaps. In a dwell time of 30 minutes it claims to fix all liquid contamination, but also to adhere to particulates preparing them to be removed by a vacuum cleaner.

Removed B- or C-contamination waste is treated with decontaminants to destroy the agents. Waste from radiological decontamination has to be stored and disposed safely. An increasing radiation hazard must be taken into consideration.

The system may be used on interior surfaces and smaller Sensitive Equipment.

Basic Technical Principle:	Physical removal.
Usable for Level of Decontamination:	Operational, thorough.
Countries of Use:	Italy and Spain.

Figure 3-9: SX34 Decontamination System (www.cristanini.it).

Table 3-17: Technology Characteristics for SX34.

N°- Requirement	Technical Specifications
Mobility	Self-contained in a trunk.
Set-up time / Strike time	15 minutes.
Capability (efficacy, capacity)	Potential removal of CBR contamination in mainly liquid form. May require multiple applications on absorbing materials.
Compatibility (other NATO decontaminants)	Compatible with almost all materials.
Interoperability	Stand-alone trunk.
Support and logistics	Self-contained, operable by a single person in IPE; needs power supply.
Environmental aspects	Requires collection and treatment of contaminated powder. Requires waste disposal.
Operational parameters	Minimal application time.
Shelf-life parameters	Long shelf life (10 years).
Training	Training in application and proper use of IPE.
Compatibility with forensic processes	Due to reactivity, probably none.

3.4.1.8.1 Evaluation of the Technology

This technology can be used on chemical, biological and radiological contamination in mainly liquid form.

Chemical Decontamination:

The active principal is a suspension of powder into a solvent. When sprayed, the solvent dissolve the chemical agent and put it into contact with the absorbent. Then, the solvent evaporates, leaving the agent trapped into the pores of the absorbent.

Biological Decontamination:

According to the manufacturer, the contaminated material is sprayed with a non-corrosive adsorbent. The adsorbent is claimed to be able to reach all areas of an item, even partly inside or in gaps. After a

processing time of 30 minutes liquid contaminations as well as particulates are said to be dissolved and can be removed by vacuum cleaning. A treatment with a special decontaminant destroys particulate bio-organisms. There are no practical arguments against the technology functioning in principle. The success in first dissolving and then inactivating bio-organisms is dependent on the chemicals used. There seems to be no detailed information on the chemicals.

R/N-Decontamination:

As a physical absorption process it may bind radioactive particulate as well as liquid contamination droplets. For radionuclides in solutions (e.g., solved in rain) that have dried on / in the material decontamination efficacy will be limited.

Advantages:

- Large surfaces covered;
- High compatibility with sensitive materials;
- Can be applied on complex surfaces;
- Stand-alone system;
- Ready and easy to use, handle and store;
- Capable of reaching small and narrow places;
- No need to dismantle the equipment to be decontaminated;
- Non-corrosive;
- No liquids;
- Non-toxic for personnel and environment; and
- Compatible with all materials, surfaces and electrical, optical, components.

Drawbacks:

- Multiple applications may be needed;
- Treatment of contaminated waste is needed;
- Limited efficacy for Type 1 (R/N) contamination;
- Radiation hazard from collected radioactive particles;
- Full removal of particles not guaranteed (e.g., inside equipment); and
- No independent information available.

Table 3-18: DOTMLPF-I Rating for Dual-Step Process Absorption/Vacuuming.

Doctrine	
Organization	+
Training	+
Materiel	
Leadership	
Personnel	+
Facilities	
Interoperability	-

3.4.1.9 Hot Air / Dry Steam [15], [16]

This hot air / dry steam chamber is for thorough decontamination of biological and chemical agents. The functional principle for the chamber is the use of high temperatures (90 – 170 °C) in a dry-steam atmosphere. The chamber needs no chemicals except water and the process is fully automatic. The chamber is designated for small and more rugged equipment, water-proof optics, weapons and individual protective gear.

Basic Technical Principle:	Destruction (accelerated hydrolysis).
Usable for Level of Decontamination:	Thorough.
Countries of Use:	Germany.

Figure 3-10: Hot Gas / Steam Chamber (WIS).

Table 3-19: Technology Characteristics for the Hot Gas / Steam Chamber.

N°- Requirement	**Technical Specifications**
Mobility	Mounted in trailers or containers.
Set-up time / Strike time	15 minutes.
Capability (efficacy, capacity)	Chamber volume 2 m³. Thorough C and B decontamination. Decontamination capacity depending on process parameters.
Compatibility (other NATO decontaminants)	No decontaminant needed. Not applicable for R/N.
Interoperability	Stand-alone systems.
Support and logistics	Self-contained. Operable by 2 persons in IPE. Needs power supply (external or battery), fuel.
Environmental aspects	No decontaminants. No hazardous waste.

N°- Requirement	Technical Specifications
Operational parameters	Average time for decontamination cycle depends on temperature and agent, ranging from minutes (170°C) to hours (< 100°C).
Shelf-life parameters	> 10 years.
Training	Training in handling and application.
Compatibility with forensic processes	Low. Cleaning process will presumably destroy most evidences.

3.4.1.9.1 Evaluation of the Technology

Chemical Decontamination:

CWAs are subject to hydrolysis (chemical decontamination) and the process time is agent and temperature dependent (ranging from minutes to hours).

Biological Decontamination:

Biological agents are destroyed at a process temperature of up to 150° C. The technology and equipment have the potential to sterilize bio-organisms due to the high temperatures. The reduction rate of different types of organisms and the time needed to achieve complete sterilization will depend on the parameters used.

R/N-Decontamination:

The process has no efficiency towards radiological agents and one must be aware of the heat resistance of the materials which undergo this treatment to avoid damages.

If modified to using water at a temperature of 85°C instead of steam and adding appropriate decontamination media, the same system is usable for radiological decontamination.

Advantages:

- No chemicals needed;
- Fully automatic;
- Can be used for biological decontamination; and
- Can be modified for use on radiological agents.

Drawbacks:

- Process time is agent and temperature dependent;
- No radiological decontamination; and
- Must be used on heat-resistant materials.

Table 3-20: DOTMLPF-I Rating for Hot Air / Dry Steam.

Doctrine	
Organization	+
Training	+

Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	

3.4.1.10 Spray-Extraction [15]

The spray-extraction system is mainly designed for interior decontamination and decontamination of large sensitive objects. Water, solvents or mild aqueous decontamination solutions (e.g., RDS 2000, BDS 2000) are sprayed with elevated pressure onto the contaminated surfaces. This loosens/solves the contamination from the surface and the liquid containing the contamination will be vacuumed concurrently. Specific spray extraction heads/tools may be used, adapted to different surfaces or surface structures. The construction of the tools and application technique avoids spreading of liquid decontaminant into the interiors and into sensitive parts. Spray Extraction is mainly designed for the decontamination of interiors, but may also be used for other larger sensitive objects.

Basic Technical Principle:	Physical removal.
Usable for Level of Decontamination:	Operational, Thorough.
Countries of Use:	France and Germany.

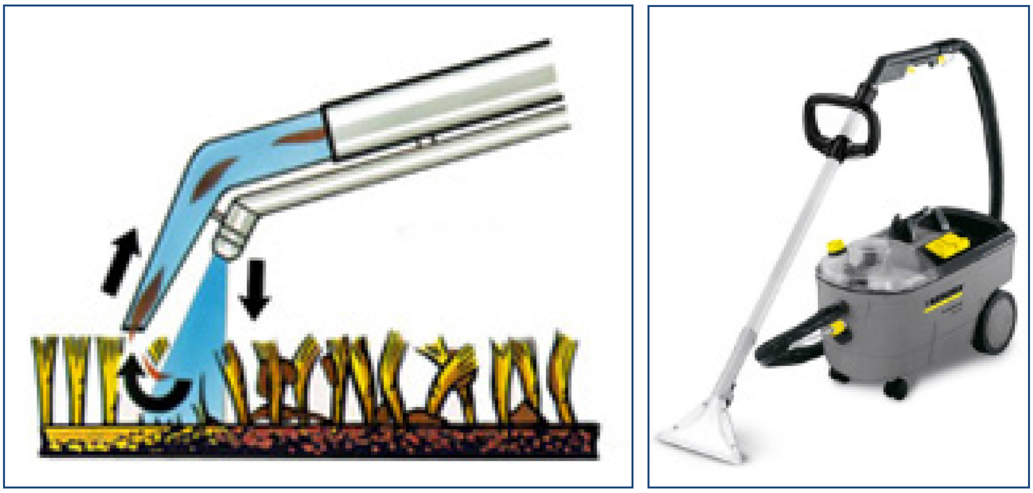

Figure 3-11: Operational Principle of a Spray-Extraction Device (Left), Civilian System (Right) (www.karcher.com).

Figure 3-12: The Fielded Spray-Extraction System, WIS.

Table 3-21: Technology Characteristics for the Spray-Extraction System.

N°- Requirement	Technical Specifications
Mobility	Handy portable devices. Mobile wheeled system of different size.
Set-up time / Strike time	15 minutes.
Capability (efficacy, capacity)	Operational and, under certain conditions, thorough R/N, B and C decontamination using specific decontaminants. Removal of contamination. Limited ability of destroying contaminants (C,B).
Compatibility (other NATO decontaminants)	Compatible to most non-corrosive aqueous decontaminants and solvents like alcohols.
Interoperability	Stand-alone systems.
Support and logistics	Self-contained. Operable by a single person in IPE. Needs power supply.
Environmental aspects	Considering safety precautions for used decontaminants. Disposal of liquid waste.
Operational parameters	Average time for decontamination cycle depends on size. Up to 2 hours for a combat vehicle interior.
Shelf-life parameters	> 10 years.
Training	Training in handling and application.
Compatibility with forensic processes	None. Cleaning process will destroy or remove most evidences

3.4.1.10.1 Evaluation of the Technology

This technology can be used on chemical, biological and radiological contamination. The spray-extraction system works by spraying active decontamination solutions onto the contaminated surfaces which is then removed by extraction. The use of degrading decontamination solutions also facilitates the waste management.

Chemical Decontamination:

This decontamination process allows removal of chemical contamination absorbed into the surface by displacement. The efficiency of the process is solution dependant. To increase the efficiency and facilitate the waste management, an active solution can be used with this system, but the contact time between the decontaminant and the surface is shorter than for classical liquid decontamination processes which will probably limit the decontamination efficiency. The level of decontamination goes from operational to thorough decontamination as function of decontaminant and material.

Biological Decontamination:

The system described disperses a decontamination solution and vacuums of the dissolved contamination. By a suitable choice of decontamination solution disinfection or even sterilization might be achieved in combination with mechanical removal. The decontaminant and/or the concentration of the active substance used can be chosen to be compatible to different types of Sensitive Equipment. The choice of decontaminant and the strength used will affect the efficiency of reduction of bio-organisms. This will most probably result in the need for longer treatment times, the need to carry out the process in several cycles or to combine the technology with another type of decontamination technology.

R/N-Decontamination:

This is the preferable decontamination technology for the decontamination of larger items and interiors of vehicles. If appropriate, exchangeable spray/extraction tools are provided with the system (size, adaption to surface, spray nozzles, pressure, etc.) and the surface of the equipment is not too complex, thorough decontamination can be achieved, at least a significant reduction of radioactive contamination will be accomplished. Every aqueous decontaminant (water, water with detergents or specifics R/N decontaminants like RDS 2000) can be used. Of high advantage is the instant collection of solved contamination in the waste water tank to be treated or stored after the process, but the increasing radiation hazard caused by this source must be taken into consideration.

Advantages:

- Wide range of application;
- Wide range of decontaminants depending on contamination;
- Targeted application;
- Dual use capability for disaster relief operations;
- Usable with good efficiency for all types of radiological contamination;
- Usable on most kind of material/equipment (water-resistant – splash-proof or higher);
- Cleaning / dirt removal ability;
- Easy to handle; and
- Instant collection of waste.

Drawbacks:

- Limited effect on complex surface structures;
- Efficiency dependent on solvent/decontaminant;
- Limited on structured surfaces;
- Collection of radioactivity in the device may lead to high dose radiation source; and
- Not usable for water/liquid Sensitive Equipment (e.g., “open” electronics like non-hardened computers).

Table 3-22: DOTMLPF-I Rating for Spray-Extraction.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	+

3.4.1.11 Vacuum Decontamination [15], [17], [18]

This vacuum decontamination chamber is for operational and thorough decontamination. The functional principle of the system is evaporation of a chemical contamination in vacuum (physical decontamination); biological decontamination can be achieved if disinfectants are injected into the system (chemical decontamination). For the decontamination of chemicals, no additional chemicals are needed; the system is an easy/ready to use technical system and has a high efficiency on most materials and complex surfaces. The system uses filtration of the exhaust air and control of the probable condensation. Looking at today's soldiers' high-tech equipment load and the high costs of such systems, it is designated with a view towards optronics and electronics and is mainly compatible with most materials.

Basic Technical Principle:	Physical removal.
Usable for Level of Decontamination:	Operational, Thorough.
Countries of Use:	France and Germany.

Figure 3-13: Sensitive Equipment Decontamination System (WIS).

Figure 3-14: Vacuum Chamber of the TEP 90 Decontamination System (WIS).

Table 3-23: Technology Characteristics for the Vacuum Decontamination Chamber.

N°- Requirement	Technical Specifications
Mobility	Mounted in trailers or container.
Set-up time / Strike time	15 minutes.
Capability (efficacy, capacity)	Chamber volume 100 – 200 litres. Thorough C and B decontamination. B – Addition of disinfectant (e.g., peracetic acid). C – No decontaminant needed.
Compatibility (other NATO decontaminants)	N/A.
Interoperability	As stand-alone system usable in combination with other systems. Power supply required.
Support and logistics	Filters and oil for vacuum pumps needed.
Environmental aspects	Filtration of exhaust gases. Disposal of waste oil.
Operational parameters	Average time for decontamination cycle – 30 minutes. Process temperature 70°C.
Shelf-life parameters	> 20 years.
Training	Training in application of different decontamination programs. Loading/unloading of equipment to be decontaminated.
Compatibility with forensic processes	High. No chemicals, no mechanical impact on material surfaces.

3.4.1.11.1 Evaluation of the Technology

This technology can be used on chemical and biological contamination, but is not applicable for radiological contamination.

Chemical Decontamination:

The process time is agent, temperature and pressure dependent. Persistent agents need higher temperature and lower pressure than volatile agents to reach optimal decontamination efficiencies. The temperature needs to be controlled to avoid condensation into surfaces, especially for persistent agents.

Biological Decontamination:

Vacuum as such is not an efficient means of deactivation bio-organisms, it needs the addition of a chemical, in this case peracetic acid. Peracetic acid is known to have good decontamination effect on spores, bacteria and virus. The equipment to be treated needs to be able to withstand the chemical. It is feasible that another type of chemical, milder to the equipment, can be chosen, but this will change the process time. Using a chemical gives a risk of condensation, which might have negative effects on the system and/or the equipment to be decontaminated.

R/N-Decontamination:

This technology is not is not applicable for radiological contamination.

Advantages:

- No chemicals;
- Easy / ready-to-use system; and
- High efficacy on most materials and complex surfaces.

Drawbacks:

- Need filtration of exhaust air; and
- Control of condensation.

Table 3-24: DOTMLPF-I Rating for Vacuum Decontamination.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	+
Personnel	+
Facilities	-
Interoperability	

3.4.1.12 Vaporous Hydrogen Peroxide [19], [20], [21], [22], [23]

The Vaporous Hydrogen Peroxide (VHP) system is for thorough and clearance decontamination. The system is compatible with most material types, data is available for many test conditions and there are commercial

delivery systems currently available. The system needs long treatment times and many decontamination cycles may be required for neat chemical contamination. It is typically used in sealed environments and may not be a viable approach when used outside or for large assets. It is designated for personal protective gear, weapons, optics, electronics and interior spaces.

Basic Technical Principle:	Destruction (chemical reaction/oxidation).
Usable for Level of Decontamination:	Thorough, Clearance.
Countries of Use:	United States.

Figure 3-15: Vaporous Hydrogen Peroxide (VHP) Systems (www.steris.com).

Vaporous hydrogen peroxide COTS systems are VHP/mVHP from Steris, USA and BQHPV from Bioquell, France.

Table 3-25: Technology Characteristics for the Vaporous Hydrogen Peroxide (VHP) System.

N°- Requirement	**Technical Specifications**
Mobility	Portable system. Requires peroxide and ammonia generators.
Set-up time / Strike time	> 1 hour.
Capability (efficacy, capacity)	Potential for thorough and clearance level C and B decontamination. Elevated efficacy may require multiple treatment cycles and extended treatment times.
Compatibility (other NATO decontaminants)	Not applicable for R/N.
Interoperability	Stand-alone systems.
Support and logistics	Self-contained. Operable by two or more personnel in PPE. Needs power supply.
Environmental aspects	Requires scrubbers and filtration system.
Operational parameters	Clearance decontamination levels may require multiple cycles (> 5). Treatment times > 1 – 2 days.
Shelf-life parameters	Shelf life of system limited by activity of peroxide ingredients.

N°- Requirement	Technical Specifications
Training	Training in handling, operating equipment, application.
Compatibility with forensic processes	

3.4.1.12.1 Evaluation of the Technology

This technology is used on chemical and biological contamination, but is not applicable for radiological contamination.

Chemical Decontamination:

The functional principle of the system is the perhydrolysis (chemical decontamination) of CWAs via the perhydroxyanion (HOO-) from vaporous hydrogen peroxide (H_2O_2). The potential integration of vaporous ammonia (NH_3) to facilitate the decontamination of CWAs not subject to acidic perhydrolysis (e.g., soman (GD)) is also possible.

Biological Decontamination:

VHP has been used regularly in the pharmaceutical industry to decontaminate manufacturing clean rooms. It is also used to sterilize packages used to store foods. It has been shown to be an effective sporicide over a range of temperatures and concentrations. There are a number of Commercial-Off-The-Shelf (COTS) VHP systems, for example VHP/mVHP from Steris, USA and BQHPV from Bioquell, France. A problem with the technology is the relatively long treatment times coupled with the need to keep the concentration of Hydrogen peroxide constant and homogenous over this time, or the need to use multiple treatment cycles. An advantage is its compatibility with most materials.

Radiological Decontamination:

This technology is not applicable for radiological contamination.

Advantages:

- Compatible with most materials;
- Many conditions are tested; and
- There are commercial systems available.

Drawbacks:

- Need long treatment times;
- Many decontamination cycles are needed for neat contamination; and
- Effective in a sealed environment, not so effective outside or for large assets.

Table 3-26: DOTMLPF-I Rating for Vaporous Hydrogen Peroxide.

Doctrine	
Organization	+
Training	+
Materiel	+

Leadership	+
Personnel	+
Facilities	(+)
Interoperability	

3.4.1.13 Enzymatic Decontamination [24], [25], [26], [27], [28], [29]

Enzymatic treatment is for operational and thorough decontamination. This may require specialized development of active enzymes (e.g., DFPases). The systems are compatible with most materials, targeted application/use of liquid decontaminant, potential dual-use for medical countermeasures, potential targeted decontamination of most toxic isomer(s) and potential use as detection capability. They may require long treatment times, have a narrow range of viable conditions (e.g., pH, temperature, salts, surface extremes may yield low efficacy), high cost and potential short shelf life. Research is going on to improve the operational use of such enzymes. The systems are designated for the decontamination of weapons, PPE and non-hardened military assets. They are not compatible with electronics.

Basic Technical Principle:	Destruction (chemical reaction).
Usable for Level of Decontamination:	Operational, Thorough.
Countries of Use:	Germany and United States.

Enzymatic commercial COTS systems are Defenz B-HD and VX-G from Genencor, USA and EDS-G from Kärcher Futuretech, Germany.

Figure 3-16: EDS-G (WIS, Left); DEFENZ (http://www.ecbc.army.mil/news/features2006.htm, Right).

Table 3-27: Technology Characteristics for Enzymatic Decontamination Systems.

N°- Requirement	**Technical Specifications**
Mobility	Readily available in storage containers. May require storage in environmentally controlled facility.
Set-up time / Strike time	Minimal, < 30 minutes.
Capability (efficacy, capacity)	Potential for elevated efficacy on impermeable materials for C and B. Limited efficacy on absorptive substrates (e.g., polymers, paints).

N°- Requirement	Technical Specifications
Capability (efficacy, capacity) (cont'd)	Not compatible with electronics. May require long treatment times, narrow range of viable conditions (e.g., pH, temperature, surface extremes).
Compatibility (other NATO decontaminants)	
Interoperability	Not compatible with active chemistries.
Support and logistics	Requires addition to aqueous/organic carrier. Sprayer capability. Collection of contaminated effluent.
Environmental aspects	Requires collection and treatment of contaminated liquid effluent.
Operational parameters	Typical application times approximately 15 – 30 minutes. May require application under controlled environmental conditions.
Shelf-life parameters	Moderate shelf life under controlled environment (e.g., 1 – 3 years). Low shelf life in non-controlled environment (e.g., < 6 months).
Training	Low burden. Training for decontamination mixing, application procedures, IPE requirements.
Compatibility with forensic processes	

3.4.1.13.1 Evaluation of the Technology

This technology is used on chemical and biological contamination. Further developments concerning enzymatic decontamination are being carried out in several countries.

Chemical Decontamination:

The functional principle for such treatment is the enzymatic degradation of CWAs. Degradation mechanism depends on the enzyme in use (e.g., catalytic hydrolysis, oxidation). Some enzymes are specific (e.g., organophosphorous hydrolase (OPH) degrades organophosphorous nerve agents) and others are polyvalent (e.g., laccase-induced oxidation, acyltransferase generates peracetic acid).

Biological Decontamination:

The inactivation of spores by a method based on oxidative enzymes has been at the centre of research activities as it is environmentally benign. A fungal laccase has been found that functions as an iodide oxidase. In aerated solutions, the laccase catalyses the oxidation of iodide to iodine and the concomitant reduction of dioxygen to water. The process is enhanced by a mediator. Results indicate that the produced iodine can be utilized to kill spores. To result in a technical application, the enzyme systems need to be improved in terms of production of enzymes, improvement in mediators, and increased efficiency in inactivation of spores as well as increased reaction velocities and specificity. Such research seems to be ongoing.

Enzyme systems are compatible with most materials. They may require long treatment times, have a narrow range of viable conditions (e.g., pH, temperature, salts, surface extremes may yield low efficacy), high cost and potential short shelf life.

R/N-Decontamination:

This technology is not applicable for radiological contamination.

Advantages:

- Compatible with most materials;
- Targeted use especially on most toxic isomer(s); and
- Dual use for medical countermeasures and detection capabilities.

Drawbacks:

- Need long treatment times;
- Narrow range when it comes to viable operational conditions;
- High cost; and
- Short shelf life.

Table 3-28: DOTMLPF-I Rating for Enzymatic Decontamination.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	
Personnel	+
Facilities	
Interoperability	

3.4.2 Future Technologies

3.4.2.1 Encapsulation in Gels/Coatings

This technology is widely spread for civilian application and has been used, for example, for clean-up purposes after the nuclear incident at Fukushima or is used for laboratory or facility decontamination in the nuclear industry. Some development has been recently conducted to extend their use for biological and chemical applications.

Strippable Gel:

The technology is based on a liquid or a gel that is spread on the contaminated surface and encapsulates radiological particles. Depending on viscosity it can be sprayed or brushed on to the surface. Within some time (up to several hours) the gel dries and solidifies to a film that can be pulled off.

Application for Sensitive Equipment decontamination has not been reported yet, but the decontamination gel is a very smooth method without aggressive chemicals or mechanical treatment, it will be taken into consideration. It adapts to complex surface structures, covers porous surfaces and to some extent gets into gaps, where it can fixate the contamination.

Basic Technical Principle:	Physical removal.

Figure 3-17: Encapsulating Gel (www.adpgel.com).

3.4.2.2 Colloidal Inorganic Gels [30], [31], [32], [33]

This technique employs gels as surface decontamination agents, which features several advantages:

- The employed formulations behave like sol under strain and are therefore easily sprayable on surfaces. At low strain, they undergo a sol-gel transition and thus form non-flowing layers on the surfaces they were sprayed on.
- These formulations dry within the decontamination time and enable the chemical attack of the surfaces to treat, in order to solubilize the radioelements present in several tens of microns of the material.
- After drying, the gel cracks to yield non-pulverulent flakes that can easily be removed from the surface by vacuum. This process considerably reduces the intervention time.
- The formed flakes concentrate the radioactivity and are compatible with most waste storage matrices without generating any liquid effluent.

To improve efficiency of absorbents and waste management, an active substance can be added to allow for the destruction of chemical and biological contaminants. Recent researches in France allow developing a spraying gel impregnated with an alkaline active substance, causing destruction of chemical and biological agents.

These technologies have been mainly designated for infrastructure decontamination, and these formulations may contain aggressive chemicals, but based on the gel properties, non-aggressive formulations may be designed for sensitive surfaces, which could be a topic for future research.

Basic Technical Principle:	Physical removal (R) or chemical degradation (CB).

Figure 3-18: Example of Vacuumable Gels (F. Cuer and S. Faure, http://www.agence-nationale-recherche.fr/Colloques/WISG2013/presentations/AAP10_GIFT-RBC.pdf).

Table 3-29: Technology Characteristics for Gels/Coatings.

N°- Requirement	**Technical Specifications**
System Name	Encapsulation in gels/coatings.
Evaluating country	Canada, France, Germany, United Kingdom and United States.
I/O/T/C-decontamination	O,T
TRL	8
Mobility	Transportable, can be applied by portable device.
Set-up time / Strike time	Quickly deployable system (< 15 minutes).
Capability (efficacy, capacity)	Mainly for R/N contaminations. Limited for C and B.
Compatibility (other NATO decontaminants)	
Interoperability	As stand-alone system usable in combination with other systems.
Support and logistics	Ready to use product, 0.2 – 1 l/m².

N°- Requirement	Technical Specifications
Environmental aspects	Stripped gel is collected and treated as hazardous waste. Low waste volume generated.
Operational parameters	Unknown.
Shelf-life parameters	
Training	No training needed.
Compatibility with forensic processes	Unknown.

3.4.2.2.1 Evaluation of the Technology

This technology has originally been developed for radiological decontamination, but has been expanded for use on biological and chemical contamination.

Chemical Decontamination:

Absorptive gels allow physical removal of chemical contamination. The combination of absorbent with an active substance allows reaching a high contact surface between agent and the active substance for rapid hydrolysis of the chemical contamination onto the contaminated surface. Addition of active substances decreases the waste hazard.

Biological Decontamination:

Biological decontamination is achieve when the gel or coating is impregnated with an active substance, and spayed in liquid form, allowing absorption and degradation of biological agents.

R/N-Decontamination:

Radiological decontamination is removed by dissolution and sequestration of particles. Efficiency of dissolution is improved by acid addition into the formulation and by increasing the contact time with surface comparing to classical liquid decontamination on surface.

Advantages:

- Generation of low waste volume;
- Large surface area covered;
- Compatible with indoor dispersion (control of spread of decontaminant);
- When dry, forms non-pulverulent flakes;
- Can be applied on complex surface structures; and
- Stand-alone system.

Drawbacks:

- Drying times depend on environmental conditions; and
- Limited efficiency on absorbing materials.

Table 3-30: DOTMLPF-I Rating for Colloidal Inorganic Gels.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	+

3.4.2.3 Micro Emulsions [34], [35], [36], [37], [38]

The micro emulsions with active components are for operational and thorough decontamination. The functional principle of such systems is the use of a mild chemical decontamination liquid which solubilizes the contamination from the surface and lets the active component (e.g., enzymes) react and degrade (chemical decontamination) in this case the CWAs. The emulsions have good solvating properties for all agents, especially thickened agents. They are designated for chemical, biological and radiological decontamination of not moisture Sensitive Equipment/surfaces. They have a Technology Readiness Level (TRL) of 7.

Recent studies have revealed that micro-emulsions depend on the presence of a reactive component, e.g., an oxidizer or a catalyst.

Basic Technical Principle:	Destruction (solubilization and chemical reaction).

Figure 3-19: Examples for Micro Emulsions: Lab-Scale (Left, WIS) and Technical Scale (Right, WIS).

Table 3-31: Technology Characteristics for Micro Emulsions.

N°- Requirement	Technical Specifications
System Name	Micro emulsions.
Evaluating country	Germany.
I/O/T/C-decontamination	T
TRL	7
Mobility	Use in existing decontamination systems (liquid decontaminant).
Set-up time / Strike time	Depending on the systems in which the decontaminant is used. Reaction time depending on reactive compound.
Capability (efficacy, capacity)	Thorough chemical decontamination. Solving of contaminants from surface (aqueous and organic). Destruction of agents by reactive compounds. B decontamination to be tested. R/N removal of particles and soluble contaminants (operational grade).
Compatibility (other NATO decontaminants)	
Interoperability	With most common liquid decontamination systems. Specific adaptations may become necessary.
Support and logistics	Micro emulsions are stable and ready to use.
Environmental aspects	Rinsing of equipment, hazardous waste water accruing.
Operational parameters	Stability of micro emulsions varying on ingredients (months to years). Need to be tested.
Shelf-life parameters	
Training	No specific training needed.
Compatibility with forensic processes	No.

3.4.2.3.1 Evaluation of the Technology

This technology is used on chemical and radiological contamination. Work is also going on for the use on biological contamination. By choice of suitable chemicals, it should be possible to achieve decontamination, disinfection or even sterilization of bio-organisms. If such research is carried out is not known at this time.

Advantages:

- Possibility to use different effectors in the same carrier for different contaminations; and
- Good solvating properties, especially for thickened agents.

Drawbacks:

- Need to work for many possible chemicals; and
- Not for moisture Sensitive Equipment/surfaces.

Table 3-32: DOTMLPF-I Rating for Micro Emulsions.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	
Interoperability	

Micro emulsions are researched in Germany by WIS, Technical University Bielefeld and Humboldt University Berlin.

3.4.2.4 Specific Solvents (Ionic Liquids / Supercritical CO_2) [39], [40]

These are new technologies that are under research mainly from nuclear industry for the removal of radioactive particles from surfaces, e.g., removing uranium from soils or in de-commissioning processes.

Both technologies could be applied on water-resistant material. They are able to solve a wide range of polar and non-polar compounds. Applications are currently still in experimental state. Chemicals may be expensive and for CO_2 high pressure and specific chambers are needed.

These technologies will not be available for an easy-to use military decontamination procedure within the next 10 to 20 years.

Table 3-33: Technology Characteristics for Specific Solvents.

N°- Requirement	**Technical Specifications**
System Name	Specific Solvents (Ionic Liquids/Supercritical CO_2).
Evaluating country	
I/O/T/C-decontamination	O,T
TRL	2 – 4
Mobility	
Set-up time / Strike time	
Capability (efficacy, capacity)	Specific liquids for C, B and R decontamination, e.g., depending on polarity.
Compatibility (other NATO decontaminants)	
Interoperability	
Support and logistics	Chemicals supply, energy.
Environmental aspects	Depending on chemical compounds.

N°- Requirement	Technical Specifications
Operational parameters	Unknown.
Shelf-life parameters	Unknown.
Training	Unknown.
Compatibility with forensic processes	Unknown.

Table 3-34: DOTMLPF-I Rating for Specific Solvents.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	+
Personnel	+
Facilities	+
Interoperability	

3.4.2.5 Cold Atmospheric Plasmas [41], [42], [43], [44], [45], [46], [47]

The Cold Atmospheric Plasmas (CAPs) are for operational and thorough decontamination. The functional principle for the systems is the use of ionized gas, made by discharge or electric arc, to degrade the biological or chemical agents. The systems need a type of gas and a high energy supply and the ionized gas can be aggressive to some surfaces. They are designated for the biological and to some extent chemical decontamination of small equipment/surfaces. They have a Technology Readiness Level (TRL) of 5 – 6. Both Germany and France are in the process of developing such systems.

Basic Technical Principle:	Destruction (oxidation).

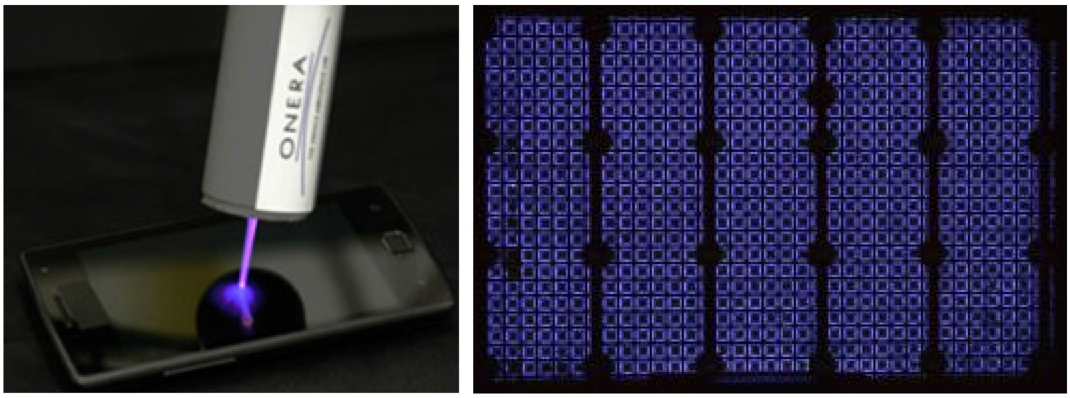

Figure 3-20: Cold Atmospheric Plasma; Spot Electrode (Left, www.onera.fr), Plate Electrode (Right, WIS).

Table 3-35: Technology Characteristics for Cold Atmospheric Plasma (CAP) Systems.

N°- Requirement	Technical Specifications
System Name	Cold Atmospheric Plasmas (CAPs).
Evaluating country	France and Germany.
I/O/T/C-decontamination	T
TRL	5 – 6
Mobility	Depending on the size of the system. Could be miniaturized enough to be transportable by one or two persons or mounted in other decontamination equipment.
Set-up time / Strike time	Very short deployment times, as the system should generally be “ready-to-use”. Short strike times for small equipment. For surfaces, strike times will depend on the size of the treated area.
Capability (efficacy, capacity)	For thorough B decontamination/disinfection. C depending on type of contamination.
Compatibility (other NATO decontaminants)	No decontaminants. Combination with other technologies in one chamber (e.g., vacuum, 2-step process) under investigation.
Interoperability	Stand-alone system. Possibly usable in combination with other systems.
Support and logistics	Power supply. Air or nitrogen gas. Energy source and gas generator could be directly integrated into a system.
Environmental aspects	No waste generated. No toxicity on people and on the environment.
Operational parameters	Precautions might be needed for gas storage. Storage of the system itself should be as easy as for any electrical device.
Shelf-life parameters	
Training	Training will be needed to learn how to operate and use the system.
Compatibility with forensic processes	Unknown but unlikely.

3.4.2.5.1 Evaluation of the Technology

This technology is mainly developed for biological decontamination, but work is going on to also include chemical decontamination Plasma is generated with ionising gas generating reactive species (free radicals, ions, electrons or photons).

Chemical Decontamination:

This technology has a potential for the degradation of a wide range of organic compounds. Application has been reported for Volatile Organic Compounds (VOCs), water treatment and research has been conduct for a few years for CWAs and TICs decontamination. Optimisation of the technology for surfaces decontamination requires comprehension of interactions between plasma, vector gas and the surface and the rate of reactive

species generated. Some studies are on-going to increase the rate of reactive oxygen species, the main oxidative species, to obtain complete degradation of CWAs.

Biological Decontamination:

CAP is a rather new development that has been given interesting applications in biology, medicine and security. The sterilizing effect of plasma treatment is the result of the total effect of different antimicrobial agents including UV-radiation, electric field, charged particles and generated radicals and other reactive species. The non-thermal plasmas maintained at room temperature at normal atmospheric pressure make them applicable to complicated geometries and heat sensitive materials. The potential for use in biological decontamination seems large. The challenge probably lies in the construction of a piece of equipment suitable for use in the field.

R/N-Decontamination:

This technology is not applicable to R/N-decontamination.

Advantages:

- Good compatibility with Sensitive Equipment; and
- Waste generated is environmentally safe.

Drawbacks:

- Need a high power supply;
- Need a vector gas for ionization;
- Need specially trained personnel to operate; and
- Aggressive to some surfaces.

Table 3-36: DOTMLPF-I Rating.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	+
Personnel	+
Facilities	
Interoperability	

Cold Atmospheric Plasma (CAP) systems are researched in France by ONERA, Plasmabiotics, Richard Lepan Consulting, CNRS (Laboratoire EM2C) and CERPEM. In Germany CAP systems are researched by Terraplasma GmbH and Garching in cooperation with WIS.

3.4.2.6 Photo Catalytic Oxidation [48], [49], [50], [51], [52]

The research is mainly focussed on two kinds of technologies studied in Germany, France and the Czech Republic.

French and German Research: Supports are impregnated with photo catalytic oxidant. Contamination is adsorbed by the support and degraded by photo catalytic oxidation. TiO_2 seems to be the best candidate material for the particle layer. Two possibilities are examined for photo catalytic action, UV in specific chambers and solar light for outdoor use. The technology is estimated to have a Technology Readiness Level (TRL) of 5.

The technology:

- Can be used for all kinds of decontamination (operational, thorough).
- Is designated for application on tissues or coatings.
- Can work mainly for chemical decontamination.
- Can be used as a self-decontamination mean when applied prior to the contamination.
- Does not need a specific processing device other than those used for classical decontamination products except a photo source device if solar light is not employed.

Czech Republic research: The Czech Republic is also intended to carry out research on photo catalytic oxidation. The principle of use is the accelerated oxidative decomposition of organic chemicals and biological agents in the presence of singlet oxygen, formed by using photo sensitizers on a phtalocyanine base. This technology can be applied on external and internal sensitive surfaces and materials of sensitive electronics and optical equipment.

Basic Technical Principle:	Destruction (chemical reaction).

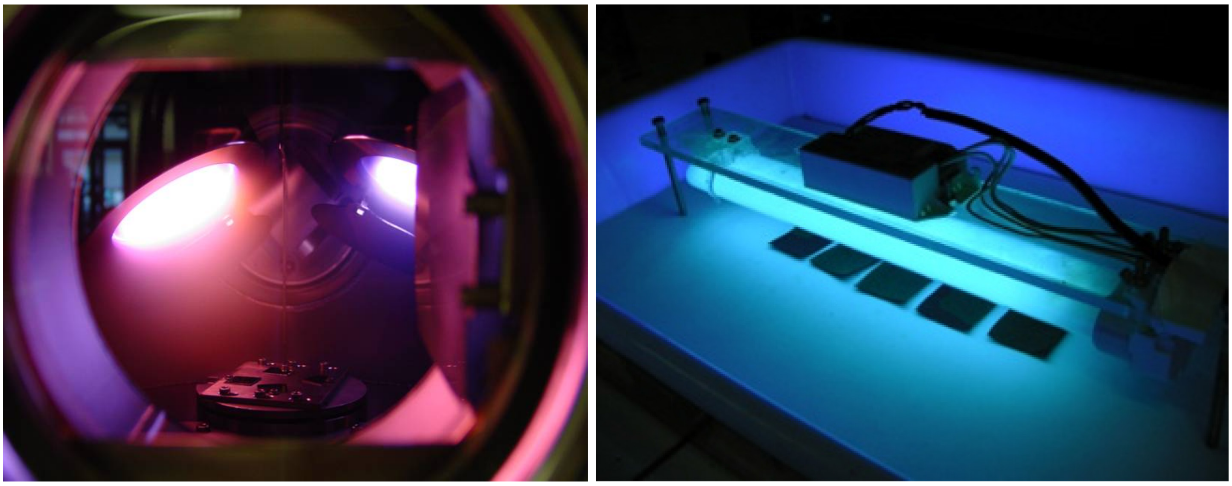

Figure 3-21: Electro-Sputtering of Nano-Scale TiO_2-Layers (Left, Detail, WIS); Irradiation of Coated Surfaces (Right, DGA CBRN Defence).

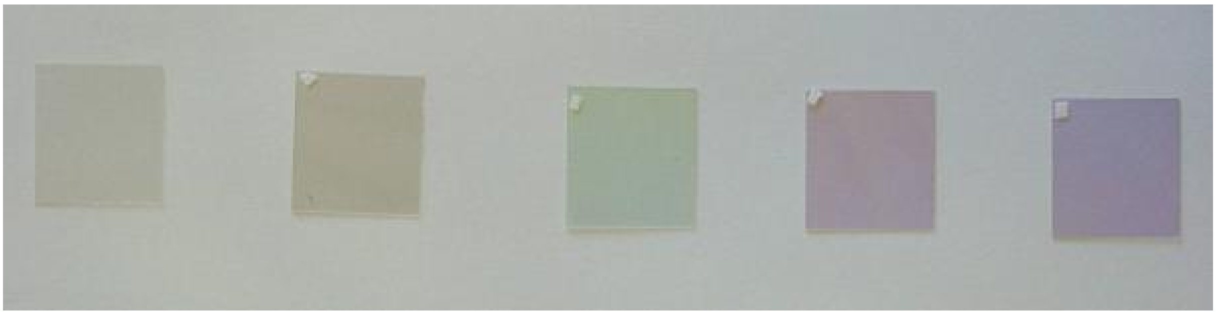

Figure 3-22: Nano-Coated Glass Plates with Varying Layer Thickness (WIS).

Table 3-37: Technology Characteristics for the Photo Catalytic Oxidation.

N°- Requirement	**Technical Specifications**
System Name	Photo catalytic oxidation.
Evaluating country	Czech Republic, France and Germany.
I/O/T/C-decontamination	T, C
TRL	1, 5
Mobility	Not available.
Set-up time / Strike time	No set up time when the technology is applied on the equipment as prevention.
Capability (efficacy, capacity)	For C decontamination.
Compatibility (other NATO decontaminants)	Compatibility with the use of decontaminants to be studied.
Interoperability	Not applicable.
Support and logistics	No logistic and support needed.
Environmental aspects	Toxicity of nanoparticles has to be studied.
Operational parameters	Unknown.
Shelf-life parameters	Depends on environment and catalyst.
Training	No training needed.
Compatibility with forensic processes	Low. Cleaning process will presumably destroy most evidences.

3.4.2.6.1 Evaluation of the Technology

This technology is for chemical decontamination of CWAs and TICs. Such kinetic degradation systems can achieve very high degradation levels compared to other active decontaminant systems which make this technology usable for thorough or even clearance decontamination. The technology has also been reported to be active against biological contamination like virus and bacteria.

Advantages:

- Good compatibility with Sensitive Equipment;
- Can reach high level of decontamination in good conditions; and
- Low logistic burden.

Drawbacks:

- Most of the catalysts are merely activated by UV light, work is in process to optimized activation by solar light;
- Long degradation process times (several hours to days); and
- Oxidative effect on the matrix.

Table 3-38: DOTMLPF-I Rating for Photo Catalytic Oxidation.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	

Photo catalytic oxidation is researched in France by the University of Strasbourg – ICS & L'ICPEES (http://icpees.unistra.fr/catalyses-et-procedes-pour-lenergie/pp/themes-de-recherche).

3.4.2.7 Surface Ablation with Lasers [53], [54], [55]

The ablation of surfaces by means of laser radiation has become a well-established dry cleaning method used for different applications:

- Paint removal (e.g., airplanes);
- Cleaning of buildings (removal of graffiti); and
- Treatment of art objects ranging from monuments and statues to paintings (which need really careful treatment).

Depending on the energy of the laser and the application parameters, strong to very smooth effects can be accomplished. This makes it of particular interest for sensible equipment decontamination.

A research project in DEU some years ago dealt with the use of this technology for the radiological decontamination of sensitive surfaces. Different laser energies and working parameters were considered, but the development of a specified decon system didn't go beyond an experimental stage.

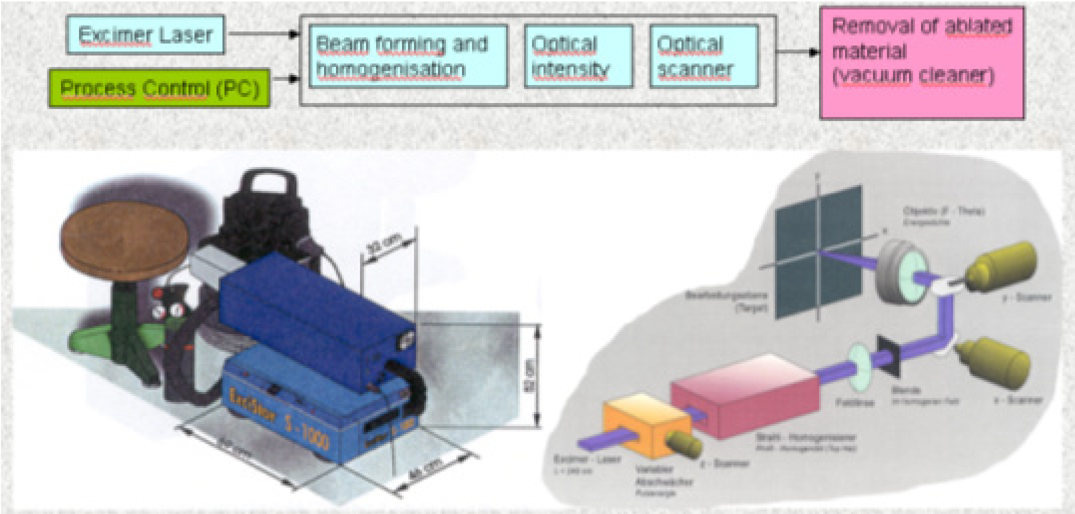

Figure 3-23: Experimental Laser Decontamination Unit [54].

Commercially available laser cleaning systems range from backpack solutions to high-power workstations or robotized systems. One of the leading manufacturers is Clean Laser (www.cleanlaser.de).

One of these systems has been tested for application on different surfaces. Due to high laser energies and application parameters, the effects on the surface vary distinctly, and less robust surface may be affected or destroyed. Therefore, it can be recommended for infrastructure (concrete, stone) or metal surfaces rather than for more weak or sensitive material.

Unlike in conventional cleaning applications, the collection of the removed particles (aspiration) is necessary for the cleaning of radioactive contaminations.

Laser radiation may be very harmful to the eyes. Skilled personnel and comprehensive protection measures are indispensable when using this technology.

Figure 3-24: Clean Laser System, Manual Application of Laser Radiation on Surfaces (WIS).

Table 3-39: Technology Characteristics for Surface Ablation with Lasers.

N°- Requirement	Technical Specifications
System Name	Surface ablation with lasers.
Evaluating country	Germany.

N°- Requirement	Technical Specifications
I/O/T/C-decontamination	O,T
TRL	6
Mobility	Transportable, different sizes.
Set-up time / Strike time	
Capability (efficacy, capacity)	Removal of upper surface layers. Efficacy (removed layers) depends on laser energy, material, time.
Compatibility (other NATO decontaminants)	
Interoperability	
Support and logistics	Power supply.
Environmental aspects	No chemicals needed, collection of removed particles.
Operational parameters	Unknown.
Shelf-life parameters	
Training	Only trained personnel. Laser protection necessary.
Compatibility with forensic processes	Unknown.

3.4.2.7.1 Evaluation of the Technology

This technology has been tested for R/N decontamination and has proved to be quite effective on robust surfaces, while application on more weak or sensitive surfaces may be limited.

The technology is used to remove contamination from the surface or remove the upper few µm of the surface material itself that may be the carrier of contaminations. Thus, other kind of contamination being it chemical, biological, TIC or just dirt may also be removed.

The high laser energy may also fully or partly destroy chemical agents or biological material. But this has not been tested in the above mentioned work.

Advantages:

- No decon chemicals needed;
- Collection of removed material; and
- High environmental compatibility.

Drawbacks:

- Laser protection needed (danger to eyes);
- Operation by skilled personnel only;
- Not applicable on every kind of surface/material; and
- Expensive.

Table 3-40: DOTMLPF-I Rating for Surface Ablation with Lasers.

Doctrine	-
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	-
Interoperability	-

3.4.3 Adapting Existing Technologies

AEP-7 defines Sensitive Equipment to include those items that cannot be decontaminated by commonly used methods such as aqueous or organic-based liquid decontaminants without degradation of the item's performance. However, materiel or equipment which can be considered as critical for mission performance, such as their functions being indispensable to the effective operation of the system, may also be considered as being Sensitive Equipment. Also, the influence of the concentration of a decontaminant has to be taken into consideration. For example, if hydrogen peroxide is used in low concentrations, it is well within the scope of its application that it or other classical decontaminants might be compatible with several types of Sensitive Equipment, if applied in the correct concentrations.

This part describes a non-exhaustive list of technologies or systems available Commercial-Off-The-Shelf (COTS) for such modified decontamination.

3.4.3.1 Active Aqueous Decontamination Solutions

Hydrogen peroxide (H_2O_2)-based decontamination solutions (e.g., SDF, Q2000, BDS 2000, CET CDS) have been developed for the last ten to twenty years due to their mild properties as opposed to more classical oxidative or alkaline decontaminant solutions. Nevertheless due to their formulations and peroxide concentrations they still show more or less corrosive effects on materials.

As described previously, hydrogen peroxide in a vaporous state show higher compatibility with sensitive materials and is in use in some NATO/PfP Nations for indoor surface decontamination and decontamination of smaller equipment.

However, even in a liquid state, hydrogen peroxide is in some applications been found useable depending on their formulation. France is using the solution Q2000 associated with the SYMODA disperser for aircraft exterior decontamination.

Hypochlorite or dichloroisocyanurate-based decontamination solutions (e.g., BX 24, CASCAD,) in certain concentrations can be compatible and usable on sensitive or non-hardened equipment. However, a concentration decrease of oxidative species is often associated with reduction of efficiency of decontamination.

Basic Technical Principle:	Destruction (chemical reaction/oxidation).

Figure 3-25: Aircraft Decontamination with French Q2000 Decontamination Solution and SYMODA Dispenser (DGA CBRN Defence).

Table 3-41: Technology Characteristics for Active Aqueous Decontamination Solutions.

N°- Requirement	**Technical Specifications**
Mobility	Used in existing decontamination systems (liquid decontaminant).
Set-up time / Strike time	Depending on the systems in which the decontaminant is used. Reaction time depending on reactive components.
Capability (efficacy, capacity)	Thorough chemical decontamination. Destruction of B and C agents by reactive components.
Compatibility (other NATO decontaminants)	
Interoperability	With most common liquid decontamination systems. When used in powder form, a formulation kit must be added for powder dissolution.
Support and logistics	Ready to use after mixing the compounds. Water supply needed for some solutions.
Environmental aspects	Rinsing of equipment. Generation of hazardous waste.
Operational parameters	Storage and transport constraints are formulation-dependent.
Shelf-life parameters	
Training	No specific training needed.
Compatibility with forensic processes	No.

3.4.3.1.1 Evaluation of the Technology

Advantages:

- High surface coverage; and
- Efficient for chemical, biological and radiological decontamination.

Drawbacks:

- Only limited application on sensitive material;
- High logistic burden (water, reactant, energy supply);
- Large volumes of effluents generated; and
- Need of rinsing process after decontamination.

Table 3-42: DOTMLPF-I Rating for Active Aqueous Decontamination Solutions.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	
Interoperability	

3.4.3.2 Aerosolization of Non-Aqueous Decontamination Solutions

Alkaline organic solutions, especially in a liquid phase, are known to be highly efficient against CWAs, but often non-compatible with sensitive materials in the classical way of use by liquid dispersion onto a surface. Still, the aerosolization of non-aqueous decontamination solutions, such as GD5/GD6 or GDS 2000 can allow for indoor surface decontamination or decontamination of Sensitive Equipment.

GD5 is said to be a low corrosive decontaminant for Sensitive Equipment decontamination and decontamination of interiors of buildings or vehicles. By using a nebulization system, like the Decofogger or Turbofogger, indoor decontamination can be done with high accessibility to the surfaces even the cracks and crevices.

Basic Technical Principle:	Destruction (chemical reaction/solvolysis).

Figure 3-26: Aircraft Decontamination by GD5 with Decofogger System. (www.oshodefence.com, www.militarysystems-tech.com).

Table 3-43: Technology Characteristics for Aerosolized Non-Aqueous Decontamination Solutions.

N°- Requirement	**Technical Specifications**
Mobility	Portable system.
Set-up time / Strike time	< 15 minutes.
Capability (efficacy, capacity)	Potential for thorough and clearance. C decontamination.
Compatibility (other NATO decontaminants)	Not applicable for R/N.
Interoperability	Stand-alone systems.
Support and logistics	Self-contained. Operable by one person in PPE.
Environmental aspects	Decontaminant dependant.
Operational parameters	Set up time < 1 minute.
Shelf-life parameters	(> 10 years).
Training	Training in handling, operating equipment, application.
Compatibility with forensic processes	

3.4.3.2.1 Evaluation of the Technology

Advantages:

- Highly effective against CWAs;
- Low corrosive in an aerosolised form; and
- High accessibility to CWAs.

Drawbacks:

- Some material compatibility issues.

Table 3-44: DOTMLPF-I Rating.

Doctrine	
Organization	+
Training	+
Materiel	+
Leadership	-
Personnel	+
Facilities	
Interoperability	

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Chapter 4 – SUMMARY

The rationale for the production of this study is the fact that over the last decades more and more equipment has found its way into the NATO forces' inventory that is not hardened against CBRN agents. As a consequence, technologies had to be developed and fielded that enable NATO forces to decontaminate equipment not developed along the lines of e.g., AEP-7 and AEP-58.

This study, for the first time, lists, describes in depth and evaluates all known technologies applicable for the decontamination of Sensitive Equipment. It can serve as a guide to the materiel developer as well as the user when a Nation has to decide upon a technology to meet its actual demands. Ideally, this study would provide the information which requirements this decision would trigger with respect to Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Interoperability (DOTMLPF-I).

This study also evaluates the potential of several new and upcoming technologies, again taking into consideration the DOTMLPF-I – schematic to the extent possible.

It does, however, for obvious reasons, not weigh one technology against the other.

4.1 FIELDED TECHNOLOGIES

Quite a few of these technologies are fielded and are reported as applicable by the countries of use; however, it has to be taken into consideration that these positions for various reasons might partially be biased.

While some technologies only execute the decontamination process to the extent of removing the contamination (which is, according to doctrine, acceptable), these are clearly at a strong disadvantage if compared to those technologies that effectively destroy contamination, thus getting rid of any hazard to the warfighter as well as the environment.

The same position applies to technologies that are only able to cope with only one kind of contamination, be it biological, chemical or radiological/nuclear as compared to cross-over technologies who can deal with the whole spectrum of CBRN contaminants and thus are preferred by the doctrinalist as well as the logistician.

The applicability of any single technology using a single decontaminant for different kinds of contamination is, however, at the best limited to operational decontamination. In order to obtain thorough decontamination, the applied technology, as well as the decontaminant, have to be tuned to the purpose.

When it comes to evaluating a technology, another problem is created by the fact that, the closer to reality a scenario under evaluation gets, the more sketchy the respective information gets. This is mostly due to security/classification issues, although it is likely that also economic interests of industrial companies play a role here.

However, starting from its resources and its level of ambition, a Nation can quickly identify the available technologies for the decontamination of Sensitive Equipment, starting out from the DOTMLPF-I – schematic.

4.2 FUTURE TECHNOLOGIES

As for the future, this study shows that several quite promising technologies are under development, e.g., cold atmospheric plasma and photo-catalytic oxidation processes, which might be able to overcome the problems mentioned above, namely the inability of a single method to perform thorough decontamination of

more than one kind of contamination. Obviously, in the case of R/N contamination, such technology has to be limited to the removal of contamination.

Over the last decades, the underlying principles of decontamination technologies have become more and more sophisticated. Serious efforts have been undertaken to replace the direct approach for CB decontamination, e.g., using strong oxidizers, with very specific, mild effectors like enzymes.

With respect to B-decontamination, the search for new decontaminants not damaging to skin ("mild" decontaminants) is a priority issue. Cold plasma as well as some enzymes seem to have the potential to become future mild decontaminants. Basic research in this area has been performed on laccases and peroxidases with respect to their capabilities to support the formation of biocidal chemical agents; moreover, Chitinase and Lysosome have been investigated for their ability to inhibit growth of Bacillus anthracis.

One thing future technologies are likely to have in common is the reverse turn back towards very basic, physical principles of decontamination.

Chapter 5 – CONCLUSIONS

As of today, there is not yet a technological capability gap with respect to the decontamination of Sensitive Equipment.

However, the Alliance, at this time, has at its disposal only limited capabilities for the CBRN decontamination of Sensitive Equipment. This is due to the CBRN threat widely not being recognized for what it is – a tool, easily available even for a very low-tech opponent, to severely reduce the technological superiority of NATO forces in a conflict.

NATO forces superiority today is to a large extent based on technological rather than numerical superiority. If C3 or C4I capabilities, which are typically executed using sensitive technical equipment, are severed by a CBRN attack, NATO forces will fall back to the same technological level as the adversary, maybe even lower. The actual threat of "low, slow, small" describes an easy method for an opponent to attack these capabilities by delivering a CBRN payload with little technological skills.

The lack of hardening of equipment contributes to this vulnerability although, taken into consideration from an early design step, hardening is not a highly cost-driving factor. In times of multiple low-intensity, asymmetric conflicts it seems the logical solution to generally identify mission-critical classes of equipment and to develop these systems in a way that they are decontaminable with respect to expected CBRN and TIH contamination. Although at first sight this seems to be an approach suited for the Framework Nations Concept, it is recommended to make this a NATO effort under the auspices of the SMART DEFENCE INITIATIVE in order to ensure maximum interoperability in Alliance operations.

The magic solution of a universal technical decontamination solution to decontaminate all kinds of equipment from all kinds of hazards is not available and will not be available within the next 10 – 15 years.

The results of this study lead to the conclusion that beyond continuing to observe the market and wait for industry to develop new, innovative technologies, NATO is well advised to invest in research in this area.

Appendix 1 – TECHNOLOGIES AND THEIR APPLICABILITY

Table A1-1: Presently Available Technologies.

Technology	Nature of Contamination			
	B	**C**	**R/N**	**Principle**
Mild Decontamination Solutions	I	I, O	(I)	Chem degradation, physical removal
Ablative Laser Technology	O?*	O, T	O, T	Physical removal
Absorptive Technologies, Dry	I	I, O	I, O	Absorption
Absorptive Technologies, Solvent Mediated	I, O	I, O	I, O	Absorption (destruction)
Washing with Surfactants (With or Without Solvents)	I	O, T	O, T	Physical removal
Accelerated Hot Air Weathering	–	T	–	Evaporation
Dry Aspiration	–	O	O, T	Physical removal
Dual-Step Process Absorption/Vacuuming	O	O, T	O, T	Physical removal, followed by destruction
Hot Gas / Dry Steam	T	T	–	Destructions by accelerated hydrolysis and thermolysis
Hot Gas / Dry Steam at 85°C	–	–	T	Physical removal
Spray Extraction	O, T	O, T	O, T	Physical removal and destruction
Vacuum Decontamination	T	T	–	Evaporation/destruction
(Modified) Vaporous Hydrogen Peroxide	T	T	–	Destruction by oxidation
Enzymatic Decontamination	(O?)	O, T	–	Catalytic destruction

Table A1-2: Future Technologies (Data are Estimated Performance Potentials).

Technology	Nature of Contamination			
	B	**C**	**R/N**	**Principle**
Encapsulation in Gels	O	O	O, T	Physical removal
Micro-Emulsions	O, (T)	T	O	Removal and destruction
Ionic Liquids (Supercritical Fluids)	T?	T?	O, T?	Removal
Cold Atmospheric Plasma	T	T	–	Destruction (oxidation)
Photo-Catalytic Oxidation	O, T?	T	–	Catalytic destruction

* Not tested.

Appendix 2 – DECONTAMINATION EFFICIENCIES OF SOME "CLASSICAL" BIOLOGICAL DECONTAMINANTS[1]

The chemicals below may be applied by any system capable of dispersing them in liquid or gaseous form, respectively, and that is compatible with the decontaminant.

Table A2-1: Decontamination Efficiencies of Biological Decontaminants.

Decontaminant	Gas/ aerosol (g/m^3)	Liquid (%)	Effectiveness Against			
			Spores	Bacteria	Virus	Rickettsia
Alcohol	-	70	-	+	±	+
Iodine	-	0,01 – 2	(+)	+	+	+
Virkon S	-	1	(+)	+	+	+
Chlorine	-	0,1 – 5	(+)	+	+	+
Phenols	-	0,5 – 3	-	+	+	+
Quarternary Ammonia Compounds	-	0,1 – 1	-	+	±	+
Chlorhexidine	-	0,05 – 0,5	-	+	-	+
Formaldehyde	3 – 10	3 – 8	+	+	+	+
Glutaraldehyde	3 – 5	1 – 2	+	+	+	+
Ethylene oxide	400 – 1000	-	+	+	+	+
Peraceticacid	2 – 10 g/m^3	0,35	+	+	+	+
Betapropiolactone	2 – 10	-	+	+	+	+

+ Good effect.

(+) Questionable effect.

± Effect varies strongly with type of virus.

\- Bad/insufficient effect.

[1] FOA-R 94-00044-4.4-SE, Swedish Defense Research Agency.

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This report provides a survey on current and future technologies for the CBRN decontamination of Sensitive Equipment and evaluates the capabilities of the different technologies to counter today's and tomorrow's CBRN threats. The document was elaborated by a group of scientists and CBRN specialists, all being members of the Hazard Management Panel within NATO Joint CBRN Defence Capability Development Group.

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14. Abstract

Allied forces must be fully prepared to respond to, and recover from, the consequences of a CBRN incident. In this context, more and more highly Sensitive Equipment has found its way into use with NATO forces. Along with this, the problem of decontamination of such equipment, which is very often deemed mission-critical, gains importance.

This study is aimed at supporting the operational specialist as well as the force builder when it comes to the issue of Sensitive Equipment decontamination.

It describes today's situation as well as provides a glimpse into the intermediate future with regards to actual and future systems for the decontamination of Sensitive Equipment. Special attention is paid to the usability of the information in this study for the operational community by applying the DOTMLPF-I schematic wherever possible.

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